EnviroGRIDS remote sensing data use and integration guideline

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Abstract:

The integration of remote sensing data from airplane and satellite into the Grid architecture will be organized in collections of freely available scenes that will be accessible though the different partners. This data will be stored on a Spatial Data Infrastructure (SDI) with its metainformation, and finally redistributed to all partners and end users. This task is responsible to build the capacity to execute remote sensing analyses by the different partners of the project. Priority will be given on land and coastal analyses (mapping and monitoring). This task will be also important for the visibility of the project outputs, illustrating different theme related to the nine "Societal Benefit Area" of GEOSS.

Earth observations by remote sensing refers to the use of imaging sensors technologies for gathering information, at different scale, on a given object or area. We propose to use medium to high resolution images, freely available or at low cost, on the internet or through specific agreements. Remote sensing scenes should be integrated into the GRID architecture and store in the SDI to be redistributed to all potential users.

This deliverable is part of work package 2 Spatial Data Infrastructure. It is covering the following points:

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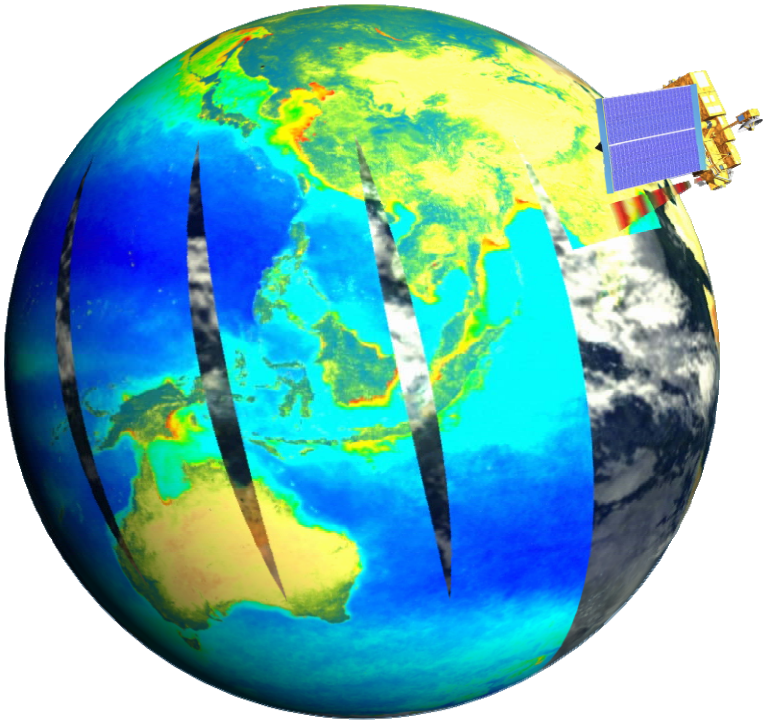
Executive summary

EnviroGRIDS project aims to gather, store, distribute, analyze, visualize and disseminate crucial information on the environment of the Black Sea Catchment (BSC). The project addresses the issues of sustainability and vulnerability by bringing several emerging information technologies that are revolutionizing the way we are able to observe the planet. EnviroGRIDS will build a state of the art Grid enabled Spatial Data Infrastructure (G-SDI) that will become one component in the Global Earth Observation System of Systems (GEOSS) targeting the needs of the Black Sea Commission and the International Commission for the Protection of the Danube River (ICPDR). Important component of such an effort is to employ as part of the G-SDI a wide range of remote sensing data sources and technologies.

EnviroGRIDS is organized into several Work Packages (WP) and WP2 is concentrating on organizing G-SDI, including, among many other aspects, the preparation, gridification and use of remotely sensed data. Task 2.4 of WP2 in particular is concerned with the deliverable D2.4 entitled Remote Sensing Data Use and Integration Guideline, which is the subject of the current document.



© Reto Stockli, NASA GSFC, Modis scanning swath

The main part of the Guideline begins with a basic introduction to remote sensing with the presentation of the passive (naturally emitting/reflecting radiation) and the active (backscattering of sensor illumination) types of remote sensing. This is followed by a comprehensive description of the types of remote sensing satellites and sensors (such as LANDSAT, SPOT, EO-1, EOS, ERS, MERIS, AVHRR, SeaWiFS, ASTER, MODIS, Ikonos, QuickBird and others) with specifications about spectral, spatial, and temporal resolutions, what they can detect, and some applications. Critical pre-processing steps, such as radiometric, atmospheric and geometric corrections, are also explained briefly.

This Guideline continues with some explanations on the main processing steps to derive meaningful information from remote sensing data. One of the most important methods for information extraction is the multispectral image classification to produce land cover/use maps or to determine change detection. The Guideline elaborates on various options for multispectral processing, such as the Unsupervised Classification (where the system is

allowed to self-generate the land cover classes); the Supervised Classification (where the non-targeted areas are classified against the user intervention by 'training' the system at known sample areas) and continues with the presentation of more specific processing methodologies such as the Spectral Angle Mapper (or hyperspectral) classification.

An important section of the document is then devoted to key areas of remote sensing applications and products. Sample product illustrations and themes considered in the Guideline include the applications from forestry; agriculture; ecology (pollution visualization and thermal remote sensing research); climate change; geology, geomorphology and lithology; snow and ice cover; water bodies and biodiversity. Land use and land cover subsection considers various land surface classification schemes as well as providing examples of change detection both in the wider catchment and in coastal zone domains.

The general introduction into remote sensing is concluded by providing a comprehensive reference sources both for remote sensing literature as well as for web resources to access remote sensing data products.

The extended introduction into general aspects of remote sensing sets the scene for the explanation of the role that remote sensing can play in serving the objectives of the EnviroGRIDS project. One of the key uses of remotely sensed land cover and land use data is the Soil Water Assessment Tool (SWAT) – a program used for hydrologic simulations, and which is to be applied in the Black Sea Catchment within EnviroGRIDS. The critical role of the remote sensing applications for hydrological modelling is concerned with various land cover classification systems and respective look-up tables, to account for the input of land cover information into hydrological model simulations. Internationally accepted classification systems are described and systematized, based on the validated science products derived from MODIS (NASA), MERIS (ESA) and other finer resolution satellite based sensors such as LANDSAT and ASTER.

Another class of baseline data source for hydrological modelling is concerned with the Digital Elevation Model (DEM) of the land's surface. Various resolution DEM products with global coverage described in the document include 30 meter resolution and publicly accessible product of the ASTER Global DEM project, released recently within the GEOSS framework; as well as the popular 90 meter near-global scale Shuttle Radar Topography Mission (SRTM) DEM.

Remote sensing can provide many other elements of data feed for hydrological modelling and these are presented further in the document. These remote sensing datasets include: soil moisture, meteorological data (rainfall, wind speed, evapotranspiration, humidity), etc. Clearinghouse reference sources are provided within the document for these types of data, including references to flood observation and discharge data sources.

The approach of EnviroGRIDS to demonstrate usefulness of remote sensing in environmental and change detection applications is to utilize the range of geographical distribution and experience of project partner organizations to consider the representative spectrum of case studies covering the watershed processes, interfaced with coastal areas of the Black Sea. Themes to be covered in case studies include biodiversity and ecosystem protection, coastal erosion, land cover change and development pressures, and the climate change impacts. These and other case and demonstration studies will feed into illustrated and annotated products for the utilization and information of governmental agencies, non-governmental organizations, and the general public education, in order to raise environmental awareness in the Black Sea region. The keynote output for these purposes will be presented in the form of the Atlas of our Changing Environment, a product similar to One Planet Many People published online by the United Nations Environment Programme (UNEP). Similarly, the popular products for internet distribution will include professional video animations depicting land surface modifications in space and time, some samples of which are included with the Guideline.

The Guideline is concluded with important recommendations for the subsequent remote sensing work under the enviroGRIDS project and contribution of this component of work into the overall G-SDI Black Sea Catchment Assessment and Observatory; envisioned usage of the grid infrastructure for remote sensing applications, as well as the coordination and interoperability aspects with other ongoing efforts to construction Grid-based digital repositories for remotely sensed data, such as the GENESI-DR and other partner projects.

1 Introduction

1.1 EnviroGRIDS @ Black Sea Catchment

The EnviroGRIDS @ Black Sea Catchment (EnviroGRIDS, 2008) aims to build a data-driven system that feeds into models and scenarios to explore the past, present and future of the Black Sea Catchment (BSC[1]), by building the capacity of scientist to assemble such a system, the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake.

Figure 1 Map of Black Sea catchment

EnviroGRIDS will build a Grid-enabled Spatial Data Infrastructure and will apply hydrological modelling across the Black Sea Catchment using gridified Soil Water Assessment Tool (SWAT) based on spatially explicit scenarios of key changes in land cover, climate and demography.

To achieve its objectives, EnviroGRIDS is organized into 7 Work Packages (WP1-WP7) with several specific tasks and deliverables. WP2 is concentrating on organizing of Grid-enabled Spatial Data Infrastructure (G-SDI), including the preparation, gridification and use of remotely sensed data from various satellite sources.

Task 2.4 of WP2 in particular is concerned with Remote Sensing Data Integration and deliverables entitled D2.4 – Remote Sensing Data Use and Integration Guidelines and D2.11 – Remote Sensing Data Services. This document initiates the production of such Guidelines and compiles the first version of the document that will be regularly updated along the project life time.

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[1] BSC in the context of this document abbreviates the Black Sea Catchment and its use should not be confused with the same abbreviation commonly used for the Black Sea Commission.

1.2 Description of work

The integration of remote sensing data from airplane and satellite into the Grid architecture will be organized in collections of freely available scenes that will be accessible though the different partners. This data will be stored on a Spatial Data Infrastructure (SDI) with its metainformation, and finally redistributed to all partners and end users. This task is responsible for building the capacity for remote sensing analyses by the different partners of the project. Earth observations by remote sensing refers to the use of imaging sensors technologies for gathering information, at different scale, on a given object or area.

There are two types of remote sensing. Passive RS uses the radiation emitted or reflected by an object. This type of RS includes for instance CCD imagery, radiometers. Active RS, such as radar or lidar, measures the time delay between the emission and its return to the sensor. It gives access to physical properties (namely height, speed, direction) of an object or area observed.

Remote sensing gives the opportunity to have access to continuous data collection and in the context of this project will be essential to monitor changes and trends in the Black Sea region/watershed (e.g. land use, deforestation, water quality). We propose to use medium to high resolution images available freely or at low cost on the internet or through specific agreements. A key list of main providers includes:

- MODIS (Moderate Resolution Imaging Spectroradiometer, NASA): http://modis.gsfc.nasa.gov/
- MERIS (Medium Resolution Imaging Spectrometer, ESA): http://envisat.esa.int/instruments/meris/
- ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer, NASA): http://asterweb.jpl.nasa.gov
- LANDSAT archives
- SPOT images

Monitoring of land cover / land use is for instance an important element for quantifying land surface characteristics for environmental management. Moderate spatial resolution space born remotely sensed data such as MODIS (The Moderate Resolution Imaging Spectroradiometer), SPOT Vegetation data or /and AVHRR will be used. Available public domain data featuring better spatial resolution (up to 250m) and superior standards of calibration, georeferencing and atmospheric correction, as well as detailed per-pixel data quality information might be utilized.

Before any classification process the images will be atmospherically corrected and registered with the UTM coordinate system. If it is necessary, a mosaic process can be used to produce just one image scene. To generate land cover maps, ISODATA unsupervised classification methodology will be applied with ancillary data.

The use of remote sensing data constitutes an effective way of achieving information about a definite area. Remote sensing, a very useful tool for monitoring and control, provides a continuous data collection so that changes in that area can be observed and early management systems proposed. Remote sensing can be used in a variety of environmental issues needing observations on land cover, land use and water quality. The outputs of this task will generate useful data for both ICPDR and the Black Sea Commission since both commissions deal with environmental sustainability issues, in terms of pollution prevention, Earth observation systems and protection the ecosystem.

1.3 Contributors

UNIGE: http://www.unige.ch/envirospace

& UNEP/GRID-Europe : http://www.grid.unep.ch

Anthony Lehmann

Dr. Anthony Lehmann is the EnviroGRIDS project initiator and coordinator. He holds a Masters Degree and a PhD in Aquatic Biology from the University of Geneva, and a Postgraduate Master in Statistics from the University of Neuchâtel. He specialized during his career in combining GIS analyses with statistical models. At the University of Geneva he is in charge of the enviroSPACE laboratory exploring Spatial Predictions and Analyses in Complex Environments.

He is sharing is working time at a 50% rate with the United Nations Environment Programme (UNEP) Global Resource Information Database (GRID) under a special agreement between the University of Geneva and UNEP. At GRID, Dr. Lehmann is responsible for organizing research activities by leading the "environmental monitoring and modelling" unit. With the EnviroGRIDS project, his personal objective is to motivate all the partners to give their best in order to improve the observation system of the Black Sea Catchment.

Gregory Giuliani

After obtaining a degree in Earth Sciences, he went on to complete a master in Environmental Sciences, specializing in remote sensing and GIS. He previously worked as a GIS Consultant for the World Health Organization, as a University tutor in remote sensing and GIS and as a GIS Developper in a local Swiss GIS company. He works at UNEP/GRID-Europe since 2001 and is the focal point for Spatial Data Infrastructure (SDI). In 2008, he also started to collaborate closely with the enviroSPACE laboratory where he begins a Ph.D thesis and works also for the FP7 ACQWA project. In enviroGrids, he is involved as WP2 leader where his objective is to coordinate SDI and Grid technology researches.

Karin Allenbach

Karin Allenbach obtains a multidisciplinary master in Earth Sciences. She pursued a postgraduated certificat specializing in remote sensing and GIS.

In 2004, she started to work at UNEP/GRID-Europe, where she was monitoring algal bloom and identifying land-based pollution on coastal water in the eastern part of the Mediterranean using low resolution imagery (SeaWiFS). Since then, she has been involved in numerous projects using low to very high resolution imagery to monitor and classify the environment on an object analysis basis.

- IMOS: monitoring re-flooding and vegetation growth on Iraqi marshlands using low resolution imagery (MODIS) http://imos.grid.unep.ch/
- SwissED: Swiss Environmental Domain classification consists on grouping together pixels of similar environment rather than geographic, creating an innovative spatial framework for environmental reporting.
- Landcover-landuse classification of Geneva's canton and surrounding based on aerial photography and medium resolution imagery (SPOT)
- Cartography of naturals habitats of Geneva's canton and surrounding based on aerial photography and medium resolution imagery (SPOT)

In EnviroGRIDS project, she will be involved in WP2 (task 2.4) as a Remote Sensing Analyst.

GeoGraphic : http://www.GeoGraphic.ge

Mamuka Gvilava

Mamuka Gvilava is engaged by the GIS and RS Consulting Center "GeoGraphic", Georgia, as the Task Manager responsible for GeoGraphic's contribution into the EnviroGRIDS Project. He is specialized in a wide range of environmental subjects with more than 10 years of experience gained with cooperative projects in Georgia and in the Black Sea region.

Physicist with education and science degree, re-expanded his field of activities to environmental and social subjects, such as integrated coastal management, environmental informatics (GIS & RS, with particular experience in setting up the coastal monitoring and information systems for Georgia), environmental and social impact assessment, as well as the application of green design and development methodologies.

He combines his practical hands-on experience in environmental management and research with wider scope of policy advice serving the Ministry of Environment as the National Focal Point on Integrated Coastal Zone Management (ICZM) and the Georgian Member of the ICZM Advisory Group to the Black Sea Commission. Mamuka Gvilava is based in Tbilisi, Georgia, and is employed by "GeoGraphic" to lead its EnviroGRIDS team in implementing WP2 (Task 2.4) and WP7.

Tamar Bakuradze

Tamar Bakuradze represents GIS & RS Consulting Centre "GeoGraphic", Georgia, in the EnviroGRIDS project. She is GIS & Remote Sensing Specialist with the background and experience in addressing environmental and integrated coastal zone management (ICZM) issues. She specialized during her career in analyzing spatial data for environment protection and natural resources management. Geographer with academic background, she is mastered in the application of Cartography/GIS/RS for environment & land management.

She was involved in several environmental projects: designing and implementing the environmental quality monitoring and information system for Georgia's coastal zone; generating the State of the Environment (SoE) reporting for national decision-makers and the wider public. In parallel to project work she is serving as the Secretary of the ICZM Working Group for Georgia.

With the EnviroGRIDS project, she will be especially involved in WP2 (task 2.4) and WP7 as the Remote Sensing Analyst and in the capacity of the Assistant to the Task Manager.

Tamar was proposed and accepted at the 1st Meeting of the Project General Assembly as the member of the EnviroGRIDS's Gender Committee.

Istanbul Technical University: http://www.ins.itu.edu.tr/cevre/personel/sozen/

Seval Sözen

Prof. Dr. Seval SOZEN is professor at the Istanbul Technical University (ITU), Department of Environmental Engineering. She received her B.Sc. degree from Environmental Engineering from ITU, Faculty of Civil Engineering in 1985. She received her graduate degrees M.Sc. (1987) and Ph.D. (1995) from the same faculty in the field of Environmental Engineering.

Dr. Sözen has 24 years of teaching and research experience in the field of Environmental Science and Technology. Her research spans environmental biotechnology (activated sludge modeling, biological nutrient removal etc.), industrial pollution control, waste management, integrated water management and water quality modeling. She has directed and supervised numerous research studies and projects in the field of wastewater management, industrial pollution control, kinetics of biological processes and integrated water management. She holds a long list of scientific publications with over 100 papers, which received more than 500 citations.

Her key personal and academic skills include; broad knowledge of environmental and other sciences, strong skills in applied environmental sciences, strong understanding of biological processes theory gained from undergraduate and postgraduate study and her research experience, proven skill in water and wastewater treatment plant design and modeling, experience in writing research and other proposals for funding and other agencies throughout her academic career, proven organizational and academic management skills, commercial and governmental consultancy experience, extensive publishing, editing, and presentation track record.

Dr. Sözen supervised five European Commission (EC) funded projects at ITU. She is also trainer in Emergency Management certified by the Federal Emergency Management Agency, USA. She was awarded an incentive by the Scientific and Technical Research Council of Turkey in the engineering branch in 2000.

She will be involved in EnviroGRIDS as the leader of WP5 and will specifically contribute in biodiversity, health and energy tasks. She will also promote WP2 in the evaluation of remote sensing data.

Cigdem Goksel

Assistant Prof. Dr. Cigdem GOKSEL is an Assistant Professor at the Istanbul Technical University (ITU), Department of Geomatic Engineering. She received her B.Sc. degree from Geodesy and Photogrammetry Engineering from ITU, Faculty of Civil Engineering in 1984. She received her graduate degrees M.Sc. (1989) and Ph.D. (1996) from the same faculty in the field of Geodesy and Photogrammetry Engineering. She was visiting scholar at Murray State University's Mid-America Remote Sensing Center (Geosciences) KY – US during six months in 1999. Her research interests are in monitoring of landuse/landcover changes and in remote sensing and GIS integration for environmental studies. She supervised several research studies and projects in the field of remote sensing and integrated technologies. She has 75 scientific publications related with different remote sensing applications such as water basin monitoring, urbanization detection, coastal line and epidemologic studies.

She will be involved in EnviroGRIDS in WP2 and WP5.

Filiz Bektas Balcik (PhD student)

Filiz BEKTAS BALCIK is a Research Associate in Remote Sensing Division of Geomatic Engineering Department at Istanbul Technical University (ITU), Turkey. She is a PhD student at ITU and her PhD subject is related with wetland vegetation discrimination and mapping by using multispectral and hyperspectral remotely sensed data. She did a part of her PhD research at International Institute for Geo-Information Science and Earth Observation (ITC), Natural Resource Department, in the Netherlands while she was a Huygens Nuffic PhD Scholar (2 years). She was involved in several environmental projects as a researcher in the field of remote sensing applications on landuse/land cover change detection, urbanization, forestry, and biophysical and biochemical characteristics of savanna vegetation (in the South Africa).

Within the EnviroGRIDS project, she will be involved in WP2 (Remote sensing data use and integration task) and WP5 (Biodiversity, Health and Energy tasks) as Remote Sensing and GIS analyst.

2 An introduction to remote sensing data

Remote sensing can be defined as the collection of data about an object from a distance without coming into physical contact with them. The science involved with the gathering of data about the Earth's surface or near surface environment, through the use of a variety of sensor systems that are usually space born or airborne, and the processing of these data into information that is useful for the understanding and/or managing of environment. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces.

Remote sensing technology has many applications in mapping landuse and landcover, agriculture, soils mapping, forestry, urban planning, archaeological investigations, military observation, and geomorphologic surveying, among other uses.

Remote sensing relies on the measurement of electromagnetic energy. The sun is the most important source of EM energy on Earth. Visible light is only one of many forms of electromagnetic energy. The total range of wavelengths is generally referred to as the electromagnetic spectrum (L.F.Janssen et al., 2001) (Figure 2). It extends from gamma rays to radio waves. Thermal, ultraviolet rays and x rays other familiar forms. All this energy is inherently similar and radiates in accordance with wave theory.

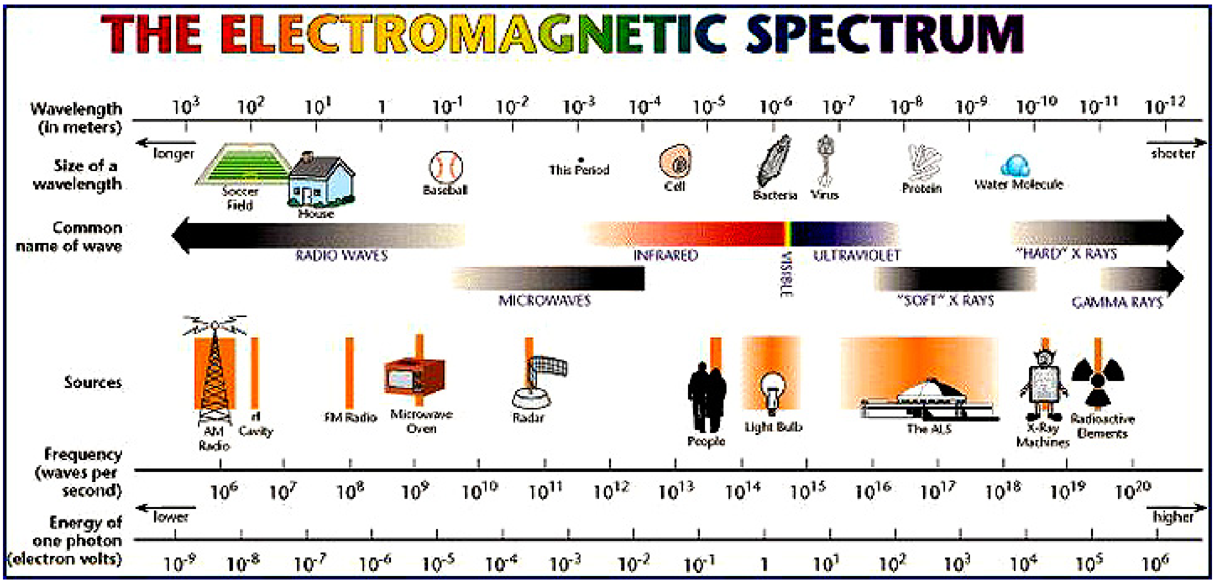

Figure 2 Electromagnetic Spectrum (http://rst.gsfc.nasa.gov/Intro/Part2_4.html)

2.1 Passive remote sensing

Remote sensing systems that measure the naturally available energy are called passive sensors. Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, observations can only take place when the sun is illuminating the Earth. There is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded (Figure 3).

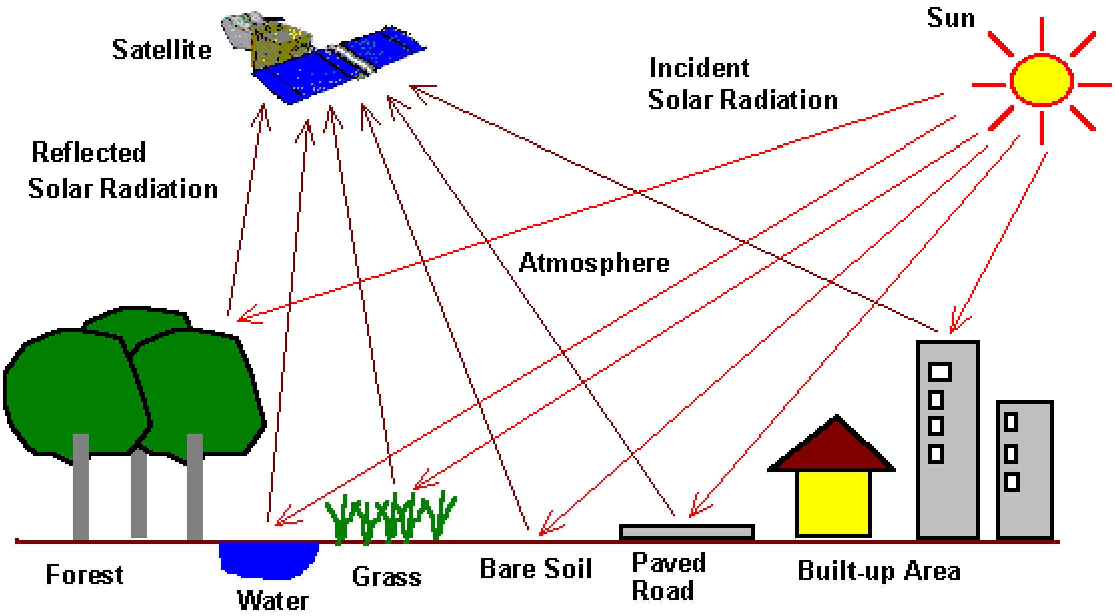

Figure 3 Physics of reflectance; energy source, transmission path, target and the satellite sensor (Remote Sensing online Tutorial NASA, http://rst.gsfc.nasa.gov)

2.2 Active remote sensing

Active remote sensing sensor provides its own energy source. The sensor transmits a microwave (radio) signal towards a target and detects the backscattered radiation. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or range) to the target. Advantages for active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Radar (RAdio Detection And Ranging) remote sensing uses microwave electromagnetic radiation to determine the Earth surface. Some examples of active sensors are altimeters, Scatterometers, synthetic aperture radar (SAR)

2.3 Available satellites and sensors

There are different types of remote sensing satellites and sensors. The annex "A. Satellite and Sensor Specification" lists the most commonly used satellites and their sensors, with specifications about spectral, spatial, and temporal resolutions, what they can detect, and applications they can be used for.

Figure 4 Most of the Earth-orbiting NASA satellites (http://rst.gsfc.nasa.gov/Intro/Part2_1.html)

2.4 Airborne remote sensing

Airborne remote sensing can be defined as the quantitative and qualitative characterization of the surface of the Earth from aircrafts by measuring the continuous, upwelling spectral radiance in each pixel (Baltsavias, 2002). Sources of imaging spectrometer data vary with different spatial and spectral resolutions. A brief summary of some currently operating systems is presented in the following Table 1.

Table 1 Airborne Systems

Acronym	Full Name	Manufacturer	Operator	Number of Bands	Spectral Range (nm)
AISA	Airborne Imaging Spectrometer for Applications	Specim, Ltd.	Specim, Ltd., 3Di, Inc., Galileo Corp.	286	450-1000
ASAS	Advanced Solid State Array Spectroradiometer	NASA	NASA, GSFC	62	400-1060
ASTER Simulator	ASTER Simulator	GER Corp.	JAPEX Gesciences Institute, Tokyo	24	760-12000
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer	NASA, JPL	NASA Ames	224	400-2450
CASI	Compact Airborne Spectrographic Imager	Itres Research		1-288	430-870
CASI-2	Compact Airborne Spectrographic Imager	Itres Research		1-288	400-1000
DAIS 7915	Digital Airborne Imaging Spectrometer	GER Corp.	DLR, Germany	79	400-12000
EPS-A	Environmental Probe System	GER Corp.		32	400-12000
HYDICE	Hyperspectral Digital Imagery Collection Experiment	Naval Research Laboratory	ERIM	210	413-2504
HyMAP	HyMAP Imaging Spectrometer	Integrated Spectronic Pty Ltd		128	400-2504
MIVIS	Multispectral Infrared and Visible Imaging Spectrometer	Daedalus Enterprise, Inc.	CNR, Rome	102	433-12700
PROBE-1	PROBE-1	ESSI	ESSI, Australia	100-200	400-2400
ROSIS	Reflective Optics System Imaging Spectrometer	DLR, GKSS, MBB	DLR	128	450-850
SMIFTS	Spatially Modulated Imaging Fourier Transform Spectrometer	Hawaii Inst. Of Geophysics		75	1000-5000
TRWIS III	TRW Imaging Spectrometer	TRW Inc.		384	400-2500

2.5 Downloading remote sensing data

In this section, addresses of web data portals are given in order to facilitate the access to Remote Sensing data. While some of these data are freely available, others have commercial costs.

Remote sensing data and products are available for the use of researchers via FTP. Online datasets may be accessed electronically through the Interface such as Earth Science Data Interface (ESDI), Warehouse Inventory Search Tool (WIST), Global Visualization Viewer (GLOVIS), and Land Processes Distributed Active Archive Center, USGS (LPDAAC).

Table 2 Main web data portals for downloading remote sensing data

Earth Science Data Interface, Global Land Cover Facility	http://www.landcover.org/index.shtml
USGS Global Visualization Viewer	http://glovis.usgs.gov/
NASA Warehouse Inventory Search Tool	http://gcmd.nasa.gov/records/NASA_WIST.html
Asterweb, Jet Propolsion Laboratory, NASA	http://asterweb.jpl.nasa.gov/NewReq.asp
Land Processes Distributed Active Archive Center, USGS	https://lpdaac.usgs.gov/
How to get Earth Observation data, ESA	http://www.esa.int/esaEO/SEM12R1VQUD_index_0.html; http://Earth.esa.int/dataproducts/accessingeodata/; http://Earth.esa.int/object/index.cfm?fobjectid=5035
Optimising Access to Spot Infrastructure for Science,	http://mediasfrance.org/oasis/
Climate Research and Environment Monitoring, CNES	http://polder.cnes.fr/
TerraSAR-X Science Service System, DLR	http://sss.terrasar-x.dlr.de/
ALOS Research and Application Projects, JAXA	http://www.eorc.jaxa.jp/ALOS/en/ra/schedule.htm
Product Service, CRESDA	http://www.cresda.cn/en/products_service.htm
Image Catalog, INPE	http://www.dgi.inpe.br/CDSR/

3 Remote sensing analyses and applications

3.1 Image Pre-Processing

Recorded image data can contain errors in geometry and in the measured brightness values of the pixels (Richards, 1993). Because of this reason, remotely sensed data need to be corrected before analysis. Description of image pre-processing methods such as geometric, radiometric and atmospheric corrections is given in the following section.

3.1.1 Radiometric and Atmospheric Corrections

The electromagnetic radiation signals travelling through the atmosphere are altered because of the process of absorption and scattering caused by gases, and aerosols within atmosphere. These atmospheric processes have a dual effect on remotely sensed data. As a result of this, remotely sensed data are not solely dependent on the spectral properties of targets on the surface of the Earth, but also on the content of the atmosphere. Changes in scene illumination, atmospheric conditions, viewing geometry and instrument response cause radiometric distortions over satellite image. Therefore, images are radiometrically and atmospherically corrected to eliminate system errors and to minimize contamination effects of atmospheric particles through absorption and scattering of the radiation from the Earth surface (Liang, 2004; Song C, 2001a; Teilet, 1986) (Figure 3).

The objective of radiometric correction is to recover the “true” radiance and/or reflectance of the target of interest (Lathrop, 1988). Units of electromagnetic radiation namely irradiance, radiance and reflectance should be considered since they will be used in radiometric and atmospheric correction procedure.

- *Irradiance* - radiant flux incident on a receiving surface from all directions, per unit surface area, W m^{-2}
- *Radiance* - radiant flux emitted or scattered by a unit area of surface as measured through a solid angle, W $ms^{-2}r^{-1}$
- *Reflectance* - fraction of the incident flux that is reflected by a medium

Conversions from Digital Number (DN) to radiance (analog signal) are conducted by using calibration parameters such as gain and offset. These parameters are available in published sources and image header files.

Atmospheric correction is a very important processing step of quantitative remote sensing because most of the inversion algorithms, such as canopy models, are based on surface reflectance that are retrieved from atmospheric correction (Liang, 2004). Atmospheric contamination is a major source of error in several applications (Du, 2002; Liang, 2001). Hence, it is common practice to remove this source of error in cases where quantitative measurements are needed, or data collected over different dates and/or areas need to be used together (Rees, 2001).

Atmospheric correction procedures are designed to minimize scattering and absorption effects due to the atmosphere. Scattering causes and increase in brightness and shorter wavelengths (visible region) are strongly influenced by scattering due to Rayleigh, Mie and nonselective scattering. On the other hand, absorption decreases brightness and longer wavelengths (infrared region) are strongly influenced by water vapor absorption (Lathrop, 1988).

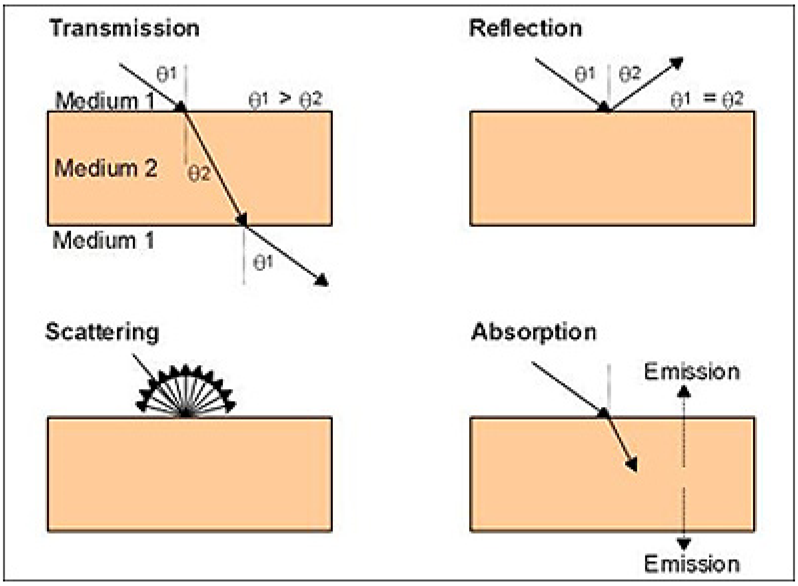

Figure 5 Any beam of photons from some source passing through medium 1 (usually air) that impinges upon an object or target (medium 2) (http://rst.gsfc.nasa.gov/Intro/Part2_3.html)

Atmospheric correction consists of two major steps: atmospheric parameter estimation and surface reflectance retrieval. There are two types of atmospheric correction techniques namely relative and absolute atmospheric correction. Different models have been developed to minimize the noise introduced by atmospheric processes on the signal received by the satellite, ranging from simple methods based on information contained in the image [e.g., Dark Object Subtraction (DOS)-based methods (Chavez, 1996) and empirical line model (Karpouzli and Malthus, 2002) to complex radiative transfer models such as a simplified method for the atmospheric correction (SMAC) (Rahman, 1994), 6S (Vermote, 1997), MODerate spectral resolution atmospheric TRANSsmittance (MODTRAN) (Berk. A. and Pukallb, 1999), and ATCOR (Richter, 1996) that simulate the atmosphere/light interactions between the sun surface and surface-sensor trajectories using scattering and transmission properties of the atmosphere.

3.1.2 Geometric Correction

There are both systematic and non-systematic geometric errors in remotely sensed imagery. The rotation of the Earth during the image acquisition, the curvature of the Earth, variations of the platform altitude, attitude and velocity, the finite scan rate of some sensors, the wide IFOV[2] of some sensors and panoramic effects related to the imaging geometry are potential reasons of these geometric errors. Detailed information about their effects is given by(Richards, 1993).

Systematic distortions can be corrected by using mathematical formulas during preprocessing and non systematic errors can only be corrected statistically by using Ground Control Points (GCPs). The most widely used geometric correction process involves selecting and identifying GCPs on a satellite image with their corresponding geographic coordinate system to derive the geometric relation between the two by determining a mathematical transformation for the correction of image geometry. Empirical geometric correction models are based on the positional relationship between points on a satellite image and points on a reference system such as geometrically corrected satellite image, topographic maps, GPS coordinates (Turker, 2004) (Figure 6). This positional relationship can be used to correct image geometry without knowledge of the source and type of the distortion. These models include conventional polynomials, affine and the rational function model (RFM)

[2] Instantaneous field of view: The field of a scanner with the scan motion stopped. When expressed in degrees or radians, this is the smallest plane angle over which an instrument is sensitive to radiation. When expressed in linear or area units such as meters or hectares, it is an altitude dependent measure of the ground resolution of the scanner (http://www.ccrs.nrcan.gc.ca/glossary/index_e.php)

(Jensen, 1996). Geometric registration error between two images is expressed in terms of an acceptable total root mean square error (RMSE), which represents a measure of deviation of corrected GCP coordinate values from the original reference GCPs used to develop the correction model. Robust and unbiased estimates of RMSE should be calculated using independent GCPs not used in model formation (Kardoulas, 1996). Several authors recommend a maximum tolerable RMSE value of ‹ 0.5 pixels (Jensen, 1996), but others have identified acceptable RMSE values ranging from 0.2 pixels to 0.1 pixels, depending on the type of change being investigated (Townshend et al., 1992).

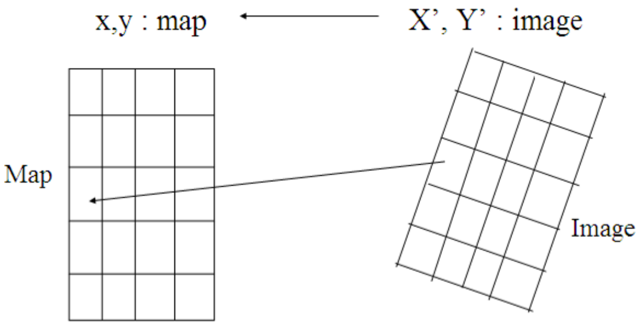

Figure 6 Transforming coordinates from one system (map) to another one (image)

1st order transformation (also referred to as an affine transformation) was effectively used to geometrically correct the images. The affine transformation can be expressed by the following equation:

$$X_i' = a_0 + a_1 x_i + a_2 y_i \quad (3.1)$$

$$Y_i' = b_0 + b_1 x_i + b_2 y_i \quad (3.2)$$

In these equations X_i', Y_i' and x_i, y_i refer the coordinates of point i in the original image and reference coordinate system, respectively. a_0 and b_0 are the translations and a_1 and b_1, a_2 and b_2 are both the rotation and scaling of x and y directions, respectively.

The selection of GCPs is very important for geometric correction. If the GCPs can be selected correctly, the derived geometric relation between the images and the geographic coordinate system will be of high quality. Different images can be projected onto the same geographic coordinate system and thematic analysis of multi-temporal data series such that spatial and temporal changes in surface properties can be detected and analyzed (Song C, 2001b).

3.2 Vegetation Indices

Vegetation monitoring by remotely sensed data is carried out by means of vegetation indices, which are mathematical transformations designed to assess the spectral contribution green plants to multispectral observations (Maselli, 1998). Vegetation indices (VIs) are mainly derived from reflectance data of red and near infrared bands to separate the landscape into water, soil, and vegetation. Vegetation indices can be divided into three parts: broad band (multispectral), narrow band (hyperspectral) and global vegetation indices. Variety of vegetation indices have been used extensively in correlating remote sensing observations with the characteristics of vegetation such as Leaf Area Index (LAI), percent vegetation cover, intercepted photosynthetically active radiation (IPAR), and green biomass

Many VIs were developed in the past three decades with the primary purposes of (1) enhancing their sensitivities to green vegetation signals and (2) reducing external effects such as those from soil and atmospheric variations (Baret F. , 1989; Demetriades-Shah, 1990; Gitelson and Merzlyak, 1996; Major, 1990; Pearson and Miller 1972; Rouse J.W., 1974; Sims and Gamon, 2002).

3.2.1 Broad Band Indices

Different vegetation indices can be applied with the broad band remotely sensed data such as Landsat, SPOT, Aster, IKONOS and Quickbird in order to determine the characteristics of vegetation. Table 3 shows some of the VIs and their references.

Table 3 Main Vegetation Indices with their references

Acronym	Name	VI	Eq.	Reference
RVI	Ratio Vegetation Index	RVI=NIR/R	1	(Pearson and Miller 1972)
NDVI	Normalized Difference Vegetation Index	NDVI= (NIR-R)/(NIR+R)	2	(Rouse J.W., 1974)
TSAVI	Transformed Soil Adjusted Vegetation Index	$TSAVI=[a(NIR-aR-b)]/[aNIR+R-ab+X(1+a^2)]$	3	(Baret F. , 1989)
MSAVI	Modified Soil Adjusted Vegetation Index	$MSAVI=(NIR+1)-(1/2)[(2NIR+1)^2-8(NIR-R)]^{1/2}$	4	(Qi, 1994)
PVI	Perpendicular Vegetation Index	$PVI=(NIR-aR-b)/(1+a^2)^{1/2}$	5	(Richardson and Wiegand, 1977)

R and NIR are spectral radiance in the red and near infrared band, respectively. L and X are soil background adjustment factors. a and b are the slope and intercept of the soil line, respectively.

2.2.2 The Narrow Band Indices

The most common indices are generally ratio indices and soil based indices that are based on discrete red and NIR bands. Vegetation reveals distinctive reflectance properties in these bands. Ratio based indices are often preferred over the soil based indices as the required soil line parameters are often unavailable or influenced by soil variability (Broge and Mortensen, 2002). The soil line originally defined by (Richardson and Wiegand, 1977) is a linear relationship between the NIR and red reflectance of bare soils and is defined by the slope and intercept of this line. Some of the narrow band indices RVI, NDVI, PVI, TSAVI and SAVI is given in Table 3.2.

In Table 4 are presented some of vegetation indices formulas. P denotes reflectance, λ_1 and λ_2 are wavelengths and a and b are the soil line coefficients for λ_1 and λ_2 respectively.

Table 4 Main vegetation indices formulas

Acronym	**Name**	**VI**	**Eq.**	**Reference**
RVI	Ratio Vegetation Index	$RVI = \rho_{\lambda 1}/\rho_{\lambda 2}$	1	(Pearson and Miller 1972)
NDVI	Normalized Difference Vegetation Index	$NDVI = \frac{\rho_{\lambda 1} - \rho_{\lambda 2}}{\rho_{\lambda 1} + \rho_{\lambda 2}}$	2	(Rouse J.W., 1974)
TSAVI	Transformed Soil Adjusted Vegetation Index	$TSAVI = \frac{a(\rho_{\lambda 1} - a\rho_{\lambda 2} - b)}{a\rho_{\lambda 1} + \rho_{\lambda 2} - ab}$	3	(Baret F. , 1989)
SAVI	Soil Adjusted Vegetation Index	$SAVI_{\lambda} = \frac{\rho_{\lambda 1}}{\rho_{\lambda 2} + (\frac{b}{a})}$	4	(Major, 1990)
PVI	Perpendicular Vegetation Index	$PVI = \frac{\rho_{\lambda 1} - a\rho_{\lambda 2} - b}{\sqrt{1 + a^2}}$	5	(Richardson and Wiegand, 1977)
REP	Red Edge	Wavelength of red edge. Value of the first derivative at the red edge $FDS_{\lambda i}=(R_{\lambda(i+1)}-R_{\lambda i})/\Delta\lambda$	6	(Dawson and Curran, 1998)

The first derivative of red edge is commonly used to enhance absorption features that might be masked by interfering background absorptions and canopy background effects (Dawson and Curran, 1998; Elvidge, 1990). A first difference transformation of the reflectance spectrum calculates the slope values from the reflectance.

Where FDS is the first derivative reflectance at a wavelength *i* that is a midpoint between wavebands *j* and *j* + 1. $R_{\lambda j}$ is the reflectance at the *j* waveband, $R_{\lambda(j+1)}$ is the reflectance at the *j* + 1 waveband and Δ_{λ} is the difference in wavelengths between *j* and *j* + 1.

2.2.3 Global Vegetation Indices

Vegetation Indices (VI) are robust, empirical measures of vegetation activity at the land surface. Time series of vegetation indices have been available since 1981 from the NOAA-AVHRR sensor, but new and improved indices have become available during recent years due to improvements of spectral resolution of the sensors. SPOT-4 VEGETATION and MODIS TERRA both provide global coverage data free of charge and are therefore widely used for vegetation monitoring.

MODIS

The MODIS vegetation index (VI) products is providing consistent, spatial and temporal comparisons of global vegetation conditions that will be used to monitor the Earth's terrestrial photosynthetic vegetation activity in support of phenologic, change detection, and biophysical interpretations.

The MODIS VI products are made globally robust and improves upon currently available indices with enhanced vegetation sensitivity and minimal variations associated with external influences (atmosphere, view and sun angles, clouds) and inherent, nonvegetation influences (canopy background, litter), in order to more effectively serve as a ‘precise’ measure of spatial and temporal vegetation ‘change’. Two vegetation index (VI) algorithms are to be produced globally for land; NDVI and EVI (Enhanced vegetation index) (http://modis-land.gsfc.nasa.gov/vi.htm).

- 250 m NDVI and QA (quality assurance) at 16 day (high resolution)
- 1 km NDVI, EVI, and QA at 16 day and monthly (standard resolution)
- 25 km NDV, EVI, and QA at 16 day and monthly (coarse resolution)

AVHRR

The Normalized Difference Vegetation Index (NDVI, based on the Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA-7 satellite, has been widely interpreted as a measure of regional to global vegetation patterns (Anyamba and Tucker, 2005).

This index is calculated from AVHRR (with 1.1km spatial resolution) measurements in the visible and infrared bands as by using the below equation:

$$NDVI = (NIR-R)/(NIR+R)$$

R and NIR are the surface reflectances in the 550–700 nm (visible) and 730–1000 nm (infrared) regions of the electromagnetic spectrum, respectively.

SPOT 4 VEGETATION

SPOT 4 VEGETATION system allows operational & near real-time applications, at global, continental and regional scales, in very broad environmentally and socio-economically critical fields with a spatial resolution of 1 km (http://www.spot-vegetation.com/).

SPOT 4 VEGETATION products:

- VGT-P products (physical values)
- VGT-S1 products (daily MVC (Maximum Value Composite Syntheses) synthesis)
- VGT-S10 products (ten-day MVC synthesis, also in degraded resolution)
- VGT - D10 products (ten day BDC (BiDirectional Composite) synthesis, also in degraded resolution)

3.3 Classification

Classification is the process of grouping pixels of images into patterns of varying gray tones or assigned colors that have similar spectral values to transfer data into information for determining Earth resources. Multispectral image classification is one of the most often used methods for information extraction. There are many classification methods to produce land cover/use map or to determine change detection (Jensen, 1996; Richards, 1993; Schowengerdt, 1997).

3.3.1 Unsupervised Classification

Spectral classes, which are groups of pixels that are uniform (or near-similar) with respect to their brightness values in the different spectral channels of the data, are grouped based on the numerical information in the data. Natural groupings or structures in the data are determined using clustering algorithms (Schowengerdt, 1997).

Iterative Self- Organizing Data Analysis (ISODATA) is the most commonly used unsupervised technique. In the first step, pixels are grouped into the number of clusters that user defined previously. These groups are called spectral classes. Classified groups are then labeled with user expertise, if the result classes are satisfactory then result classified image is used for further analysis. If the result classes are not satisfactory then numbers of clusters or some other statistical parameters such as separation distance, covariance values are changed and classification is conducted again till satisfactory result is achieved (Figure 7).

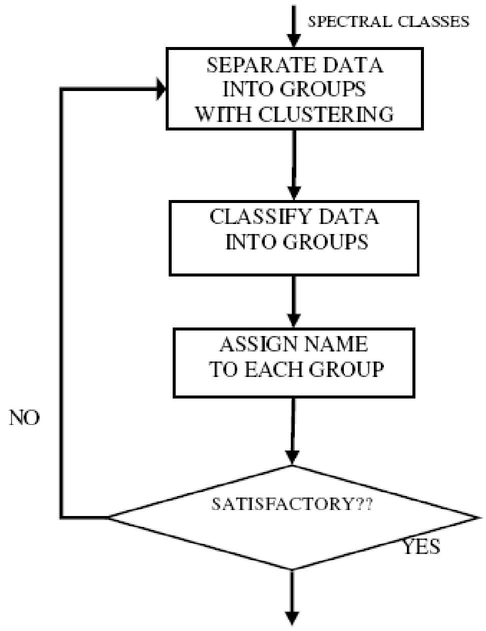

Figure 7 Unsupervised Classification Schema (Adopted from NASA tutorial)

3.3.2 Supervised Classification

In supervised classification, spectrally similar areas on an image are identified by creating ‘training’ sites of known targets and then extrapolating those spectral signatures to other areas of unknown targets (Schowengerdt, 1997). Training sites in the imagery are homogeneous representative samples of the different surface cover types. It relies on the *a priori* knowledge of the location and identity of land cover types that are in the image. These are called information classes. Topographic maps and some other ancillary data are required to select appropriate training areas. The computer is trained using the numerical information in all spectral bands for the pixels comprising training areas to recognize spectrally similar areas for each class. Steps of supervised classification are presented in Figure 8. Different types of supervised classification methods have been applied for different applications;

- Maximum likelihood,
- Parallelepiped,
- Minimum distance

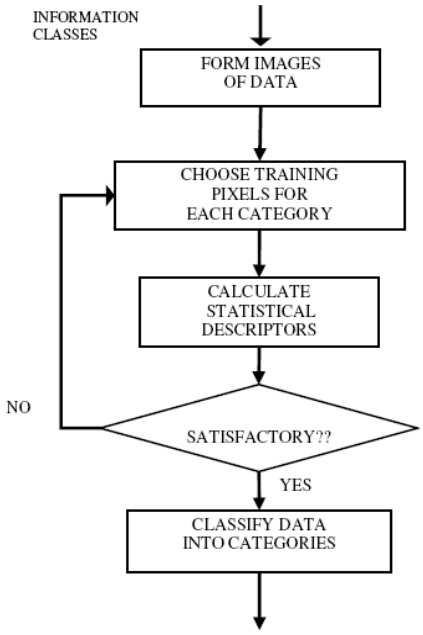

Figure 8 Supervised classification schema (adopted from NASA tutorial)

3.3.2.1 Maximum Likelihood Classification

Maximum likelihood classification is the most common supervised classification method used with remote sensing data. Although the maximum likelihood classifier is a conventional statistical classification technique that allocates each pixel to the class with which it has the highest likelihood of membership (Schowengerdt, 1997). The basis of the maximum likelihood classification is the probability density function. The maximum likelihood classifier is considered to give more accurate results than parallelepiped classification however it is much slower due to extra computations.

3.3.2.2 Parallelepiped Classification

The parallelepiped classifier uses the class limits and stored in each class signature to determine if a given pixel falls within the class or not. The class limits specify the dimensions (in standard deviation units) of each side of a parallelepiped surrounding the mean of the class in feature space. If the pixel falls inside the parallelepiped, it is assigned to the class. However, if the pixel falls within more than one class, it is put in the overlap class (code 255). If the pixel does not fall inside any class, it is assigned to the null class (code 0). The parallelepiped classifier is typically used when speed is required. The drawback is (in many cases) poor accuracy and a large number of pixels classified as ties (or overlap, class 255).

3.3.2.2 Minimum Distance Classifier

Minimum distance classifies image data on a database file using a set of 256 possible class signature segments as specified by signature parameter. Each segment specified in signature, for example, stores signature data pertaining to a particular class. Only the mean vector in each class signature segment is used. Other data, such as standard deviations and covariance matrices, are ignored (though the maximum likelihood classifier uses this). The result of the classification is a theme map directed to a specified database image channel. A theme map encodes each class with a unique gray level. The gray-level value used to encode a class is specified when the class signature is created. If the theme map is later transferred to the display, then a pseudo-color table should be loaded so that each class is represented by a different color.

3.3.3 Spectral Angle Mapper (SAM) classification

The Spectral Angle Mapper (SAM) is a physically based hyperspectral classification technique by determining the spectral similarity between an endmember spectrum and a pixel spectrum in an n dimensional space, by calculating the angle between the spectra (Kruse and Barloon, 1993). Smaller angles indicate closer matches to the reference spectrum. Since this method uses only the direction of a vector and not its length, it is insensitive to illumination and albedo. The spectral angle can be calculated by equation (2.6.1):

$$\alpha = \cos^{-1}\left[\frac{\sum_{i=1}^{n} t_i r_i}{\sqrt{\sum_{i=1}^{n} t_i^2}\sqrt{\sum_{i=1}^{n} r_i^2}}\right] \qquad (2.6.1)$$

where n is the number of bands; *i t* is test spectrum, *i r* is reference spectrum, α is spectral angle. In general, pixels belonging to the same class have small spectral angle, and spectral angles of pixels of different types are large.

3.4 Object-based image analysis (OBIA)

Traditionally image analysis is implemented on a pixel basis, i.e. each pixel will be analyzed individually, neglecting spatial photo interpretive elements like texture, context and shape. With the increase in spatial resolution, one classification target won't be represented by a single pixel but by a group of them with increasing intra-class variability. Consequently the statistical separability between classes is reduced and the classification results may show the well known high resolution problem of salt-and-pepper effect (Jinguo and Zheng, 2007).

On an object-based image analysis (OBIA) the image will be initially segmented (splitted), by regrouping similar adjacent pixels to form meaningful objects. This will overcome the problem of salt and pepper effect and assess intrinsic characteristics on spatial and spectral scale. This approach is akin to the way humans conceptually interpret their vision to understand an image (Figure 9).

Figure 9 Creation of meaningful objects (roofs, trees, shadow, street) by segmentation of an aerial photography (25 cm resolution)

Customarily used in biomedical imaging, object-based methods with their multiscale approaches are especially suited for the monitoring, modeling and management of our environment.

This is confirmed by a steadily growing community of RS/GIS practitioners that currently use image segmentation for different geographic applications (i.e., forestry, habitat mapping, urban mapping, mineral exploration, transportation, security, etc).

A key objective of OBIA is to develop methods and tools reproducing (and or exceeding) the human interpretation of RS images in automated/semi-automated ways. This will increase repeatability and production, while reducing subjectivity, labour and time costs (Hay and Castilla, 2006).

Segmentation techniques could be distinguished into methods based on global and local behavior (Kartikeyan et al., 1998). Globally data are grouped according the analysis of the feature space, whereas local merging is based on spectral differences within small neighborhood.

Bellow a general description of the object-based approach and different segmentation technique extracted from wider known commercial software for object-based image analysis, *Definiens* (previously named eCognition).

Segmentation is based on Fractal Net Evolution Approach (FNEA) which is a region-growing technique based on local criterion starting at pixel level. Objects are consecutively pairwise merged using an average minimum heterogeneity criterion weighted by their size. Homogeneity takes into account both spectral variance (color) and geometry (shape) criterion (Figure 10).

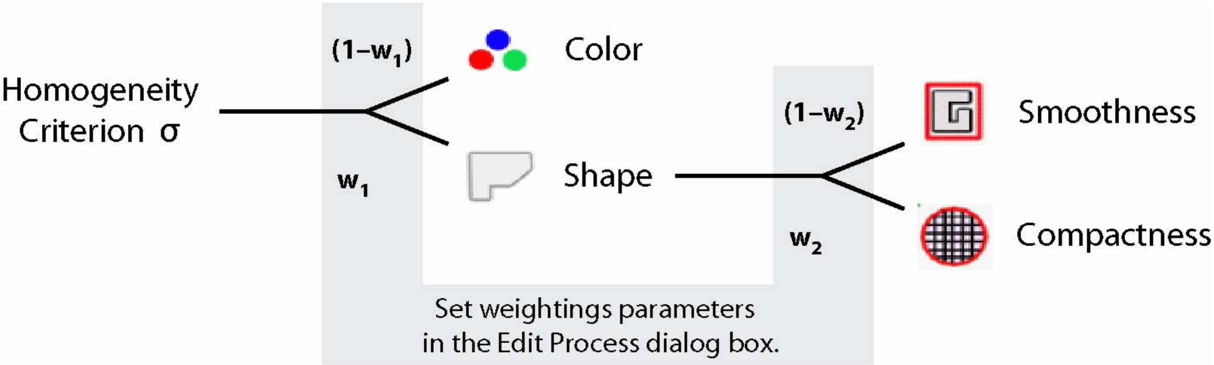

Figure 10 Weighted components of the homogeneity criterion, User guide Developer 7, Definiens.

This software offers a wide range of top-down (region dividing/splitting) or bottom-up (region merging/growing) segmentation algorithms. Moreover multiple segmentation levels can be created above the basic pixel level providing a hierarchical structure for following image analysis.

Image objects together are performing a network environment which provides much more information than a single pixel. Every object is linked horizontally and/or vertically to its neighbors allowing access to their context (Figure 11). Moreover each grouped pixel will offer wider information on their color, their texture and their form.

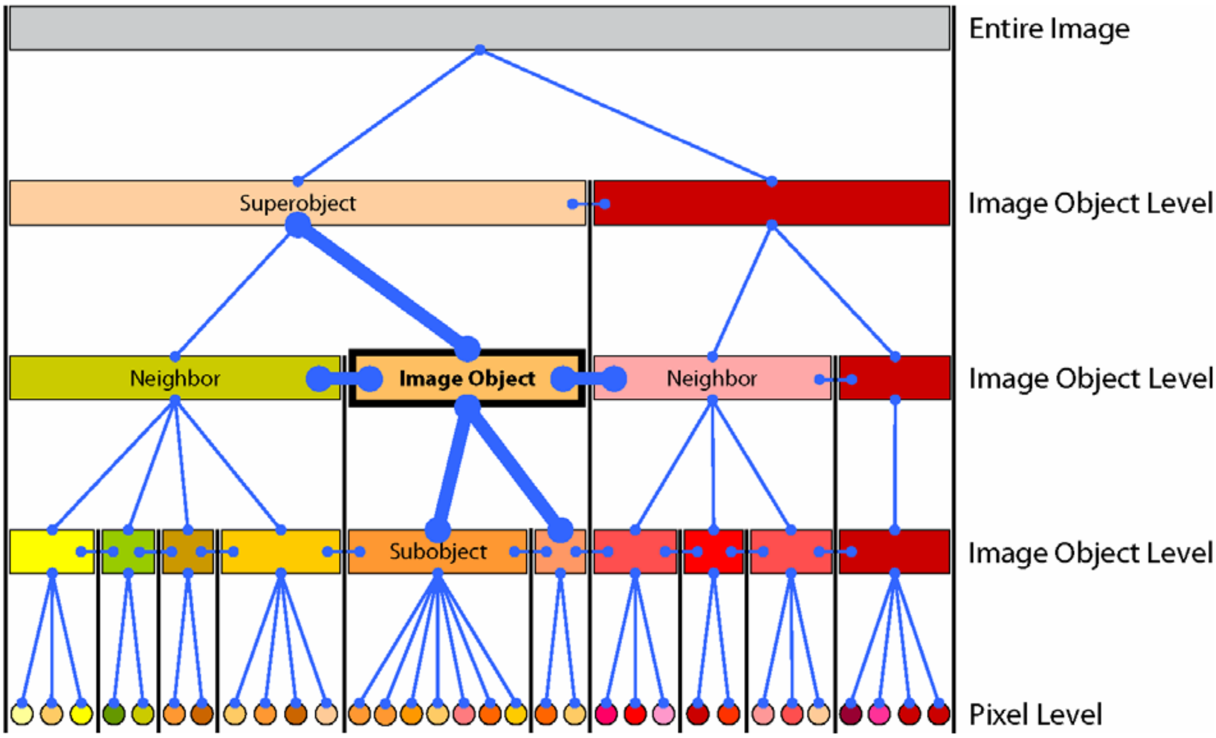

Figure 11 Multiresolution segmentation scheme. Each image object knows its context, it is linked to its neighbors, its superobject and its subobject. Definiens developer 7, user guide.

For consistency reason, each subobjects are subdividing their superobject and inversely each superobject are merging their subobjects always preserving the border of objects previously created.

Other advantages of this powerful software are the possibility to integrate ancillary thematic layer on the segmentation as well as classification stages, and the full automatisation of the developed solution.

3.5 Main remote sensing applications products and case studies

The use of remotely sensed data for solving spatial based problems depends on the use of additional data such as maps, vector data (administrative borders, water bodies, roads and etc.), their attributes, and field collected data. Geographic information system (GIS) is an efficient tool that can be used together with remote sensing technology for different field of applications. However GIS and remote sensing applications should be considered in three basic levels as local, regional and global depending on coverage area. Remote Sensing Technology is found in various fields that require analysis of natural and/or mankind resources observable from the Earth surfaces (Campbell, 1996).

In the following parts of this section, information of some basic remote sensing applications are given. More detailed information can be obtained from different web sites (e.g. http://www.asdi.com/remote-sensing/applications and http://rst.gsfc.nasa.gov/Front/tofc.html).

3.5.1 Vegetation

Vegetation studies can be divided in different groups of studies focusing on agriculture, forestry, ecology and natural/man transformed vegetation.

Agriculture: Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices. Remote sensing technology offers efficient and reliable tools for collecting the required information in order to map crop type. Besides providing a synoptic view, remote sensing can provide information about the vegetation health.

Agricultural applications of remote sensing include the followings:

- crop type classification
- crop condition assessment
- crop yield estimation
- mapping of soil characteristics
- mapping of soil management practices

Forestry: Forests play an important role in balancing the Earth's CO2 supply and change, acting as a key link between the atmosphere, geosphere, and hydrosphere. Remote sensing technology provides quickly identifying and discriminating various forest types.

Forestry applications of remote sensing include the following subjects:

1) Reconnaissance mapping: Objectives to be met by national forest/environment agencies include forest cover updating, depletion monitoring, and measuring biophysical properties of forest stands. In this context, studies on forest cover type discrimination and agroforestry mapping are performed.
2) Commercial forestry: The inventory and mapping applications such as collecting harvest information, updating of inventory information for timber supply, broad forest type, vegetation density, and biomass measurements are important subjects of commercial forestry companies and resource management agencies. Remote sensing is used effectively for especially clear cut mapping / regeneration assessment, burn delineation, infrastructure mapping / operations support, forest inventory, biomass estimation, and species inventory.
3) Environmental monitoring: Conservation authorities are concerned with monitoring the quantity, health, and diversity of the Earth's forests (http://ccrs.nrcan.gc.ca). For these purposes current technologies as remote sensing and GIS are used for monitoring deforestation (rainforest, mangrove colonies), species inventory and so on. Information derived from monitoring studies are used for environmental protection such as watershed protection (riparian strips), coastal protection (mangrove forests).

Ecology: Satellites represent excellent means to monitor threats and damages on natural resources as well as on human infrastructures and activities. For instance strong hurricanes can cause dramatic damage on wetlands, shorelines, and forests. Much obvious damage is imposed on vegetation by forest fires and grassland burns. Also, normally very easy to see are the destruction and deposits associated with sand storms. Dust storms brought about by nature but sometimes made more severe because of human land practices can affect large regions. These kinds of ecological problems can be monitored in near-real time by using both high resolution and geostationary satellites. In some cases as oil spill monitoring medium resolution optic and radar imagery can also be used (http://rst.gsfc.nasa.gov/).

In the example below, airborne hyperspectral remote sensing was used to map the simultaneous distribution of foliar nitrogen (an attractant for grazers and browsers) and polyphenol (a deterrent) in South Africa, Kruger National Park mopane savannas to determine whether the pattern reasonably concurs with the ecological knowledge of the area (Figure 12 and Figure 13) (Skidmore, 2009).

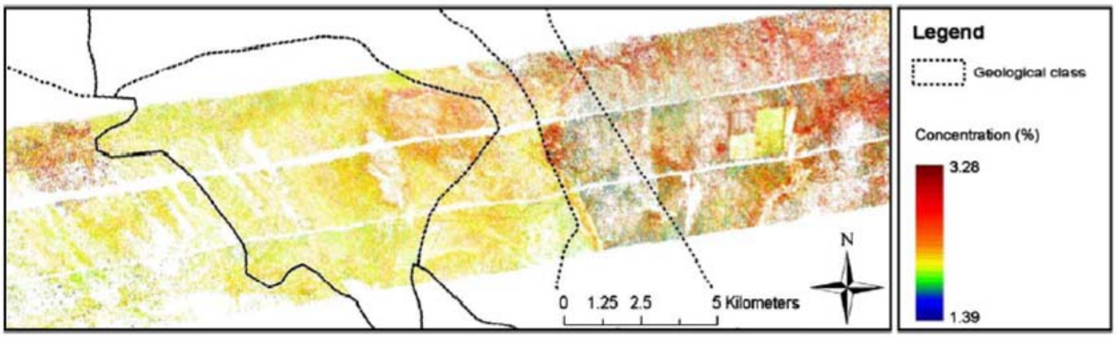

Figure 12 Foliar nitrogen concentration for mopane trees and shrubs (percent).

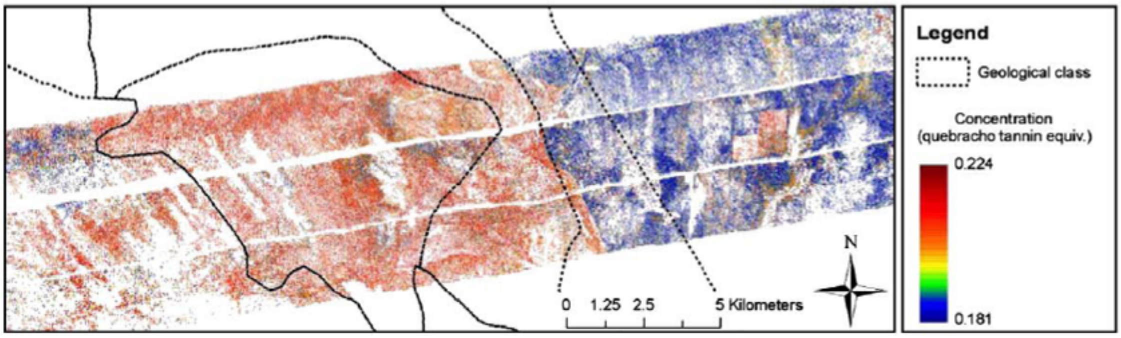

Figure 13 Total polyphenol concentration for mopane trees and shrubs

(quebracho polyphenol equivalents in gg−1).

Another good example of ecosystem monitoring and capacity building project was yield by UNEP's Post Conflict Branch (PCoB) in collaboration with UNEP/DEWA/GRID-Europe from November 2004 to December 2006 (http://imos.grid.unep.ch).

The objective of this UNEP project was to monitor a transboundary wetland ecosystem shared between Iraq and Iran. Mesopotamian marshlands were formerly covering an estimated surface between 15'000-20'000 km^2. Satellite imagery dating from 2000 was showing 90% loss of the wetland due to a drastic reduction of water entering the marshes (Figure 14).

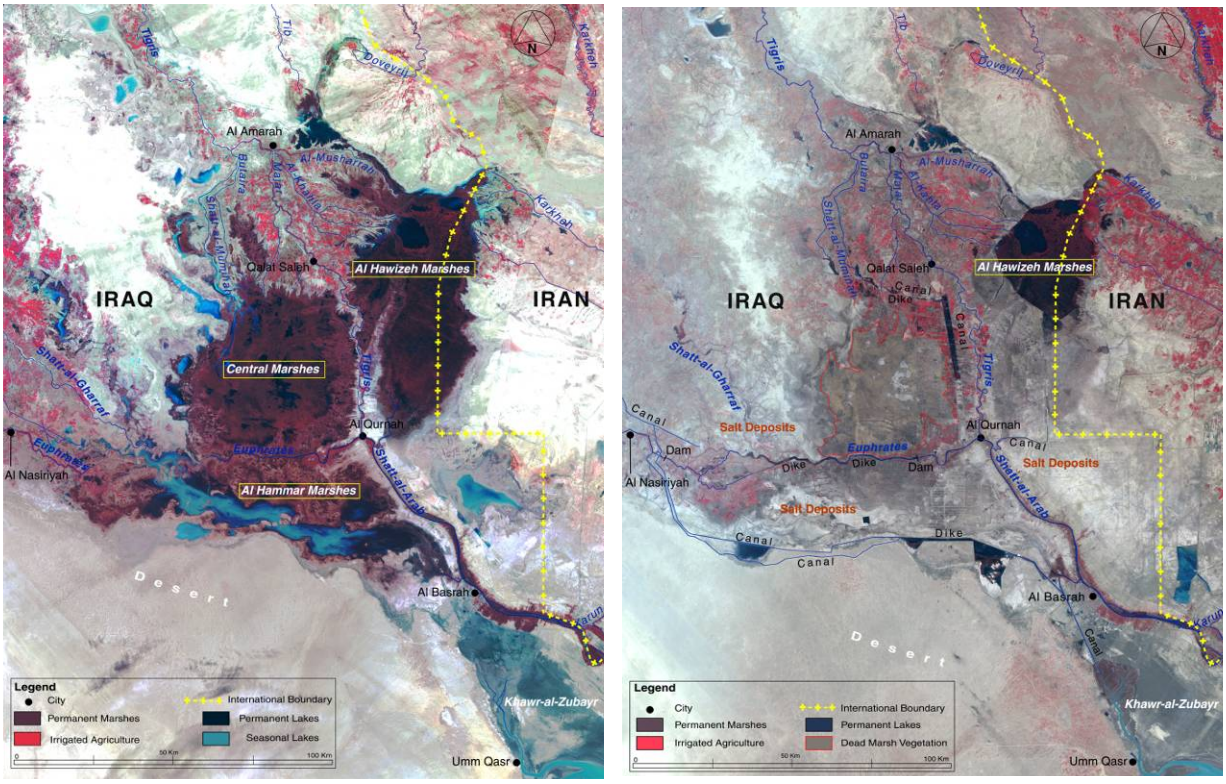

Figure 14 Landsat image of the Mesopotamian marshlands in 1973-76 (left) and in 2000 (right), UNEP/DEWA/GRID-Europe, 2001.

Since mid-2003 the destruction of dykes and drainage canals has led to the reflooding of the marshes. Since January 2003 until December 2006 MODIS images have been classified (Figure 15) on a bi-weekly basis, revealing the wetland recovering of more than 60% of the original surface.

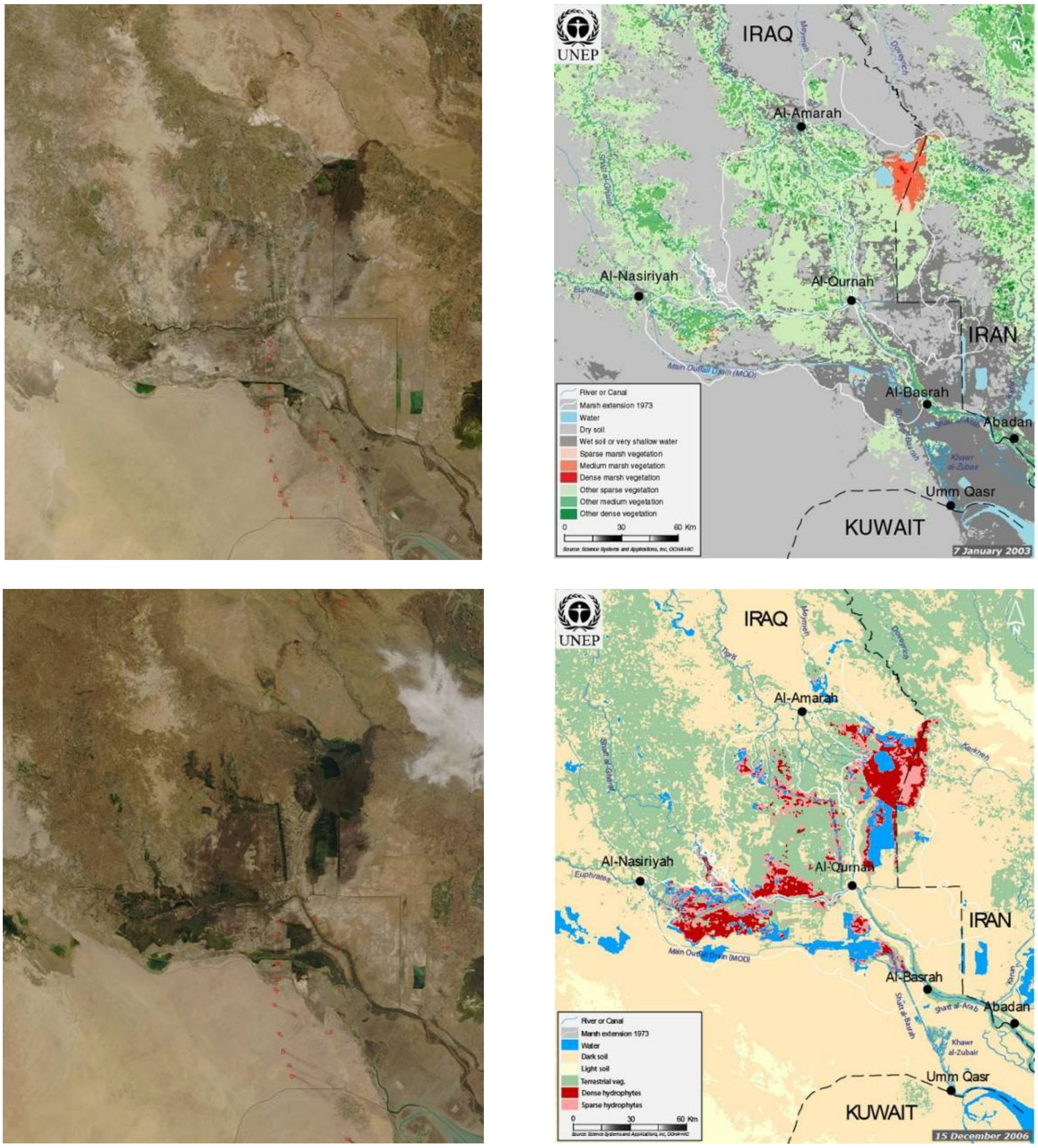

Figure 15 Modis Terra images (left) used to derived simplified map (right) of Mesopotamian Marshlands (on top, 7th of January 2003, bottom on 15th of December 2006)[3]

The last phase of the project was completed by a total system handover to Iraqi partners. Two weeks of intensive training course was held in Geneva, followed by three scientists from the Ministry of Water Resources (Centre for the Restoration of Iraqi Marslands) and Nature Iraq/Iraq Foundation, in order to transfer the methodology. They were also provided by educational materials, archives data, software and computers. Finally, distance support (by phone and web conferencing) was offered for several months, until their complete autonomy.

[3] Keeping the same methodology, map's colours have changed during ongoing project

3.5.2 Climate Effects

Remote sensing applications involve monitoring different aspects of the Earth's system. Data collected through remote sensing can be used effectively in climate change studies. As global change occurs on a daily basis, information from oceanography, plant physiology, and landscape ecology research forms the basis for climate change models. Applications such as plant canopy studies, soil analysis, hydrology studies (including snow and ice studies), general atmospheric studies, and light energy research can provide important data to these models (http://www.asdi.com/remote-sensing/applications/climate-effects).

3.5.3 Geology and Geomorphology

Most of the geoscience studies require thematic and quantitative information to be extracted from remote sensing imagery. With existing satellite data and a new generation sensors, Earth scientists have access to spatial and temporal data that can provide insights into scale dependent processes, environmental change, and Earth-system dynamics. The modeling and analysis of topography represents a significant advancement in producing geologic information, although challenges remain. Two unique challenges include understanding multi-scale topographic effects on sensor response, and ways to integrate remotely sensed data and topographic information, so that spectral, spatial and contextual information can be used (Bishop, 2001).

Imaging sensors such as Landsat, ASTER, AVIRIS, HyMap and Hyperion have been used for geological mapping, for geomorphology applications and the evaluation of changes due to natural events such as volcanic eruptions, floods, and Earthquakes, and even to indicate subtle shifts in mineralogic composition. The critical aspects of these studies are supported by ground truth data (http://www.asdi.com/remote-sensing/applications/geology-and-mineral-analysis.)

Remote sensing technologies have been used effectively to provide lithological and structural information in geological science and detailed information can be found in (Lillesand, 1994).

In the example below, Landsat 5 TM and SPOT HRV Panchromatic images and a digital elevation model based on 1:25,000 topographic maps were used to delineate the fault in North Anatolian Fault zone, Turkey. Figure 16 and Figure 17 illustrate enchanced detailes of the study (Kaya, 2004).

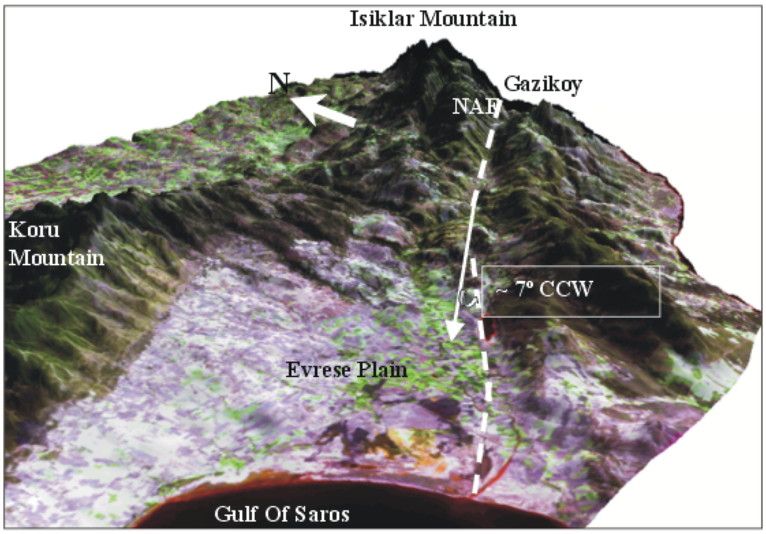

Figure 16 Enhanced data Gaziköy-Saros region

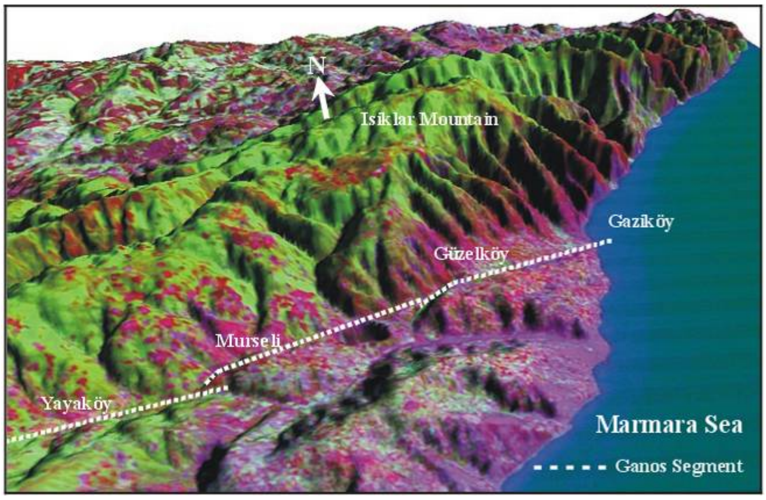

Figure 17 The Gaziköy-Saros fault segment on merged Enhanced data

3.5.4 Snow and Ice Research

One of the early applications for spectral observations was the study of snow and ice characteristics as a way of better understanding the Earth-atmosphere radiation balance. Concurrent directional-hemispherical and angular spectral reflectance studies have also shown correlations between snow reflectance and grain shape and size, hardness index, density, liquid water content, and snow temperature. Applications include climatology, avalanche monitoring, water management, and under-ice photo-biological studies (http://www.asdi.com/remote-sensing/applications/snow-and-ice-research).

3.5.5 Inland Water Bodies Research/ Hydrospheric Research

High spectral resolution observations of water bodies have led to a better understanding of natural water body absorption and transmission properties, phytoplankton ecologies, algae blooms, and heat flow layering. By analyzing the water-reflected radiance, researchers can infer the water-leaving radiance values without taking in-water measurements. This allows researchers to better interpret satellite imagery of water bodies. In-situ measurements can be used for interpretation and field validation of satellite imagery and other direct applications, such as determining underwater visibility and military laser limits, predicting the status and migration of fish, managing sediment discharge, and developing climate models (http://www.asdi.com/remote-sensing/applications/oceanography-and-inland-water-bodies-research).

Hydrologists and meteorologists determine water depth increase, location and extent of water bodies, and sea floor by using remotely sensed data.

3.5.6 Biodiversity Research

Biodiversity is one of the most important resources for mankind on Earth. It is the essential basis for the functioning of natural ecosystems and of great relevance not only for the livelihood of people but also for various technical, agricultural and economic aspects. Biodiversity is currently undergoing rapid changes often associated with a remarkable loss in species richness.
Biodiversity studies can help to understand the current situation of the sensitive natural areas such as wetlands, flooded forest (Igneada), rain forests, savanna and etc. for sustainable management with the help of satellite images and field studies.

3.5.7 Land Use & Land Cover Research

Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Identifying, delineating and mapping land cover is important for global monitoring studies, resource management, and planning activities. Identification of land cover establishes the baseline from which monitoring activities (change detection) can be performed, and provides the ground cover information for baseline thematic maps.

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year to year. This knowledge will help to develop strategies for conservation, conflicting uses, and developmental pressures. Land use studies include the removal or disturbance of productive land, urban encroachment, and depletion of forests.

Land cover / use studies are multidisciplinary in nature, and thus the participants involved in such work are numerous and varied, ranging from international wildlife and conservation foundations, to government researchers, and forestry companies. Regional and local authority and government agencies have an operational need for land cover inventory and land use monitoring, as it is within their mandate to manage the natural resources of their respective regions. In addition to facilitating sustainable management of the land, land cover and use information may be used for planning, monitoring, and evaluation of development, industrial activity, or reclamation. Detection of long term changes in land cover may reveal a response to a shift in local or regional climatic conditions, the basis of terrestrial global monitoring.

Land use applications of remote sensing include the following (http://ccrs.nrcan.gc.ca) subjects:

- natural resource management
- wildlife habitat protection
- baseline mapping for GIS input
- urban expansion / encroachment
- routing and logistics planning for seismic / exploration / resource extraction activities
- damage delineation (tornadoes, flooding, volcanic, seismic, fire)
- legal boundaries for tax and property evaluation
- target detection - identification of landing strips, roads, clearings, bridges, land/water interface

Land cover map provides a delineation of resources and special land use classification systems have been developed such as USGS and CORINE classification (Anderson, 1976; Moos and Wyatt, 1994).

Change detection of land cover and land use is a fundamental input for monitoring, planning, management and environmental studies, such as landscape dynamics, urbanization, natural hazards, manmade risks and environmental impacts.

Temporal changes of land use/cover classes of the mega city Istanbul between the years of 1992, 1997 and 2005 were examined for the management and decision making process. Post classification technique was applied for processing the data change detection (Figure 18). The comparison was done between the years 1992–1997, 1997–2005, and 1992–2005 (Balik Sanli et al., 2007)

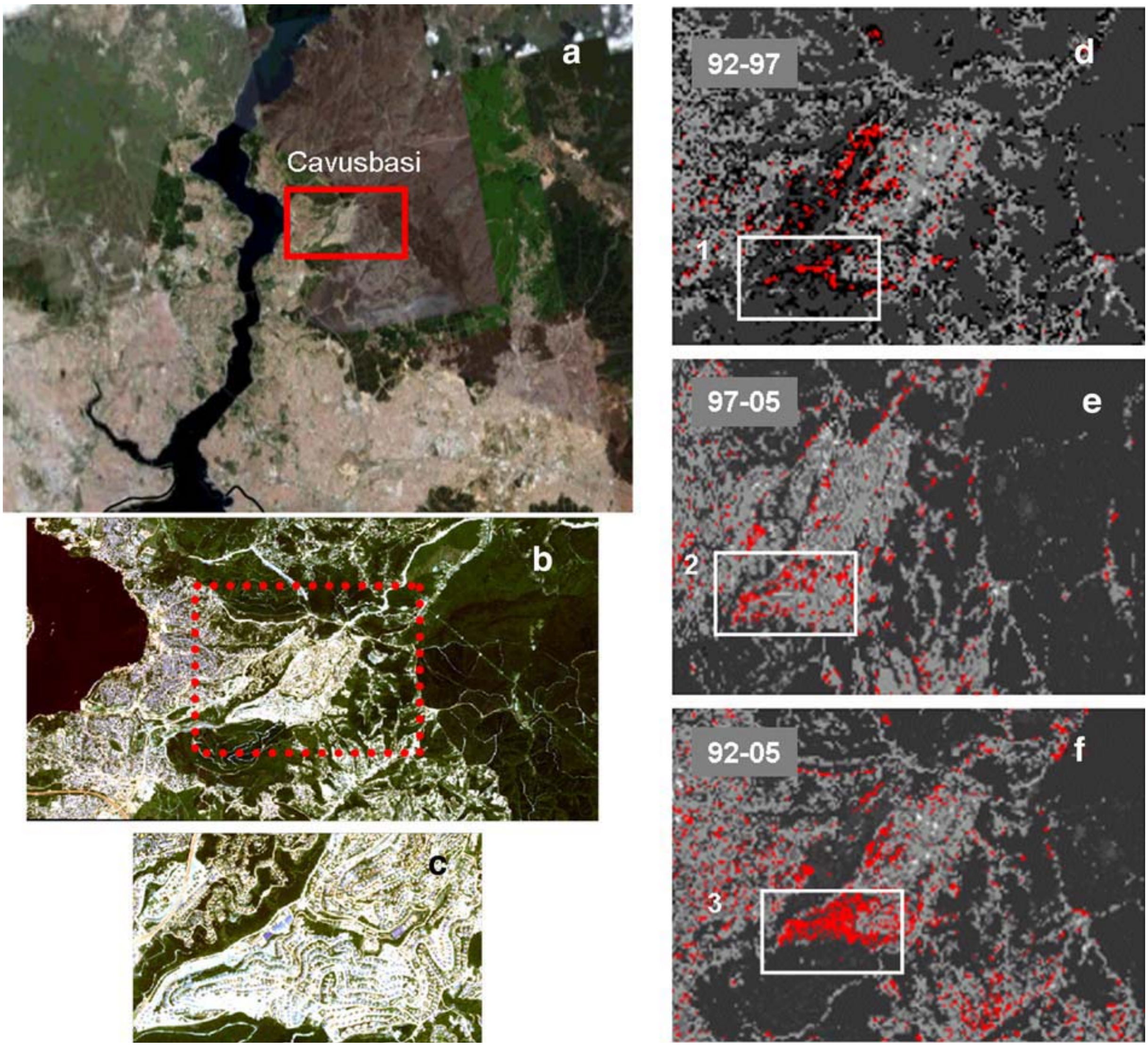

Figure 18 Changes of Cavusbasi Region a: location of Cavusbasi Region b: and c 2004 dated IKONOS image of Cavusbasi d: forest to urban changes between the years of 1992–1997 e: forest to urban changes between the years of 1997–2005 f: forest to urban changes between the years of 1992–2005

3.5.8 Coastal Zone Research and Management

Black Sea coastal zone covers territories of its littoral countries Bulgaria, Georgia, Romania, Russian Federation, Turkey, and Ukraine. Management of complex and dynamic systems such as coastal zones are require integrated approaches which would allow for rational and coordinated measures to bring together numerous contradicting and overlapping interests. The coastal countries have reached a consensus on the necessity of reconstruction of existing management systems in compliance with the regionally agreed approaches of Integrated Coastal Zone Management (ICZM).

ICZM pilot projects were implemented in several locations along the coast to test methodologies for spatial planning for the Black Sea coastal areas, see Antonidze (2009): in Gelendzhik resort in Russian Federation, Akçakoca district of Turkey and Tskaltsminda coastal community in Georgia (for further references see ICZM Pilot Project 2004, 2007 and 2009).

Remote sensing and GIS were important instruments applied when defining baseline conditions, analysing spatial manifestation of changes taking place in these coastal areas, and defining functional zoning for the purposes of coastal management.

Gelendzhik, Russian Federation

The spatial planning methodology developed for the Black Sea area was first tested in the Gelendzhik resort (Russian Federation) in 2002–2004 with EuropeAid project support. Assessment of importance and sensitivity of natural components (water, soil, vegetation, fauna, and sea environment) was carried out, natural and administrative restrictions for land use were identified, ecological and inter-sectoral conflicts revealed, and zoning solutions proposed (Figure 19Figure 20).

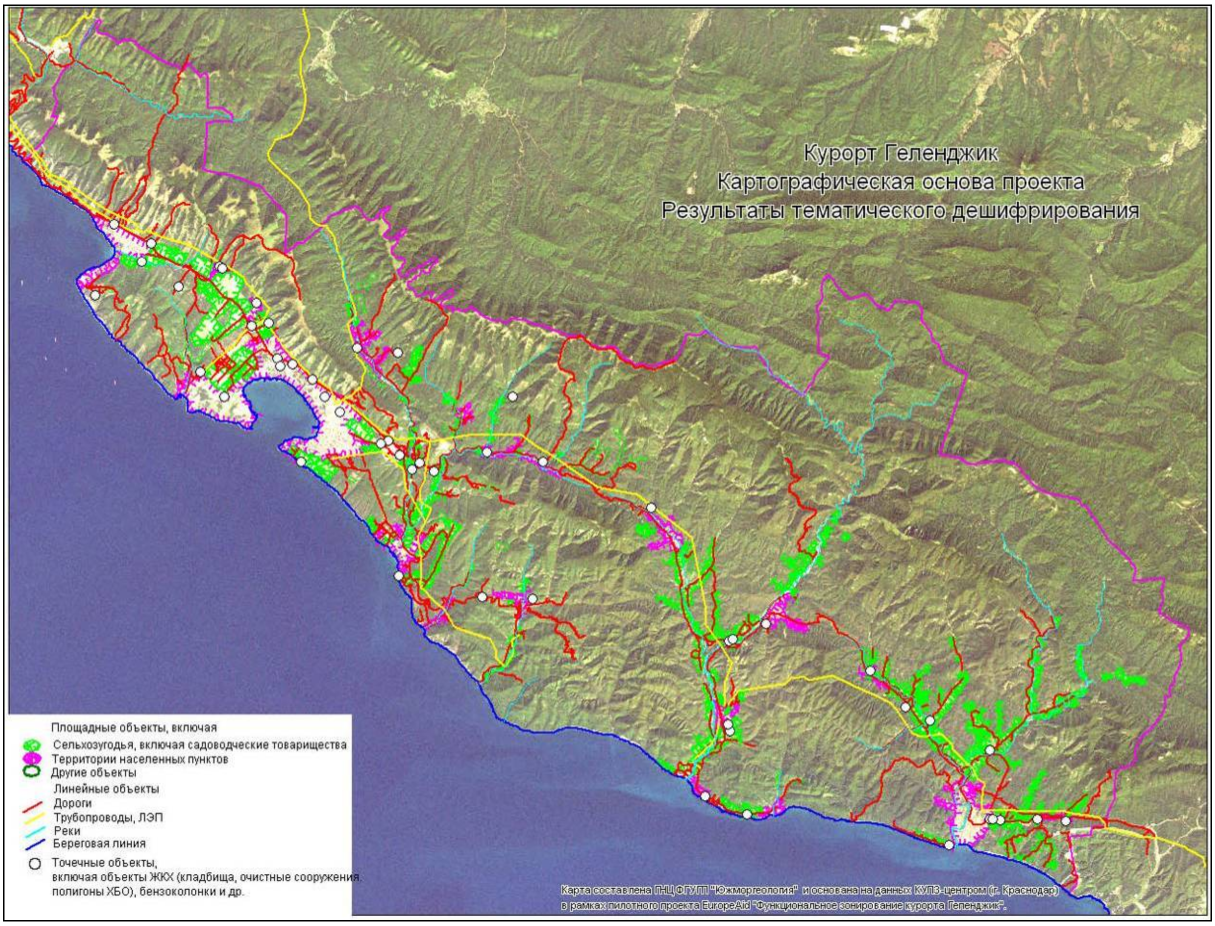

Figure 19 Backdrop image for mapping the pilot area

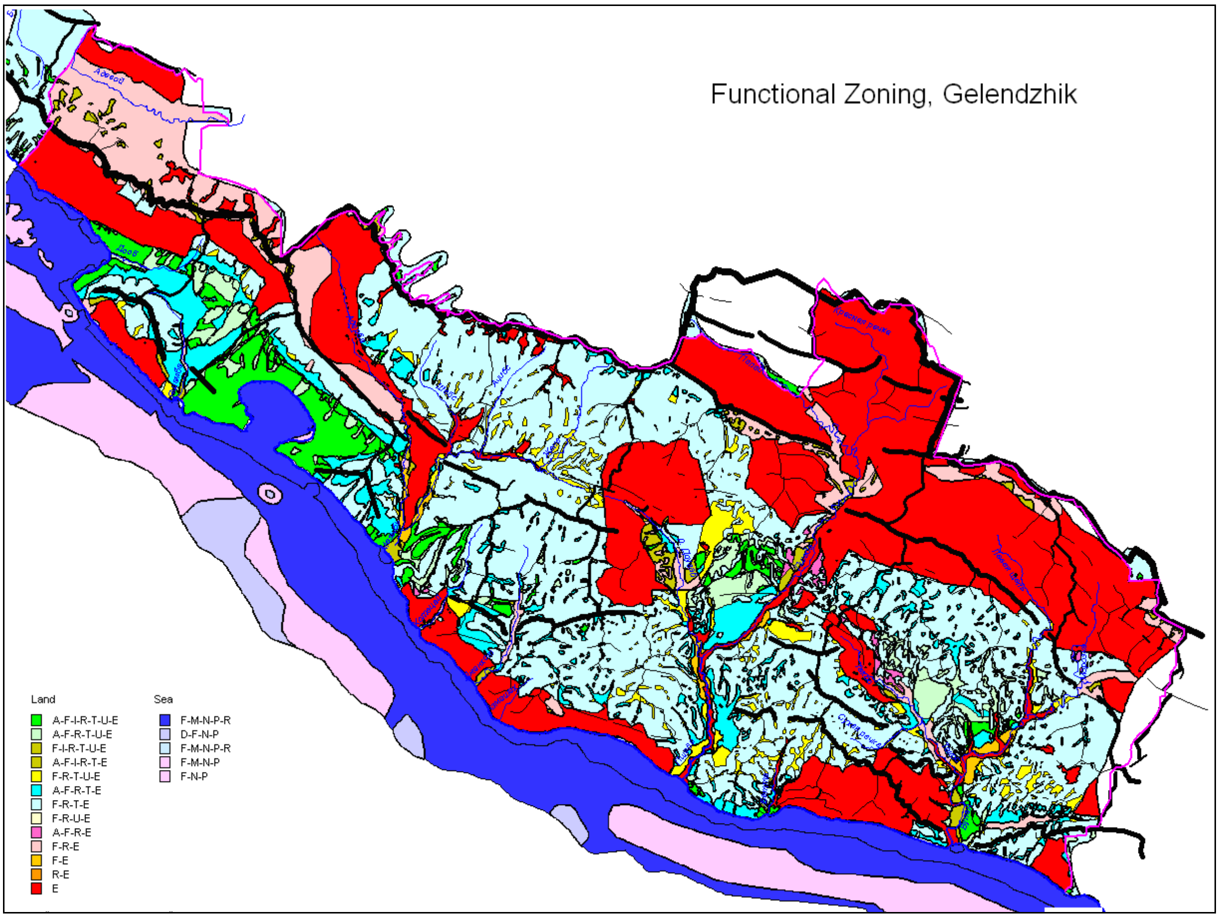

Figure 20 Resultant functional zoning map for Gelendzhik

Akçakoca, Turkey

Another application of ICZM methodology for spatial planning in Akçakoca district along the Black Sea coast of Turkey was applied by Istanbul Technical University. Specifically the emphasis was given to displaying the sectoral conflicts in the form of digital maps to the decision makers with the aim of presenting the actual land use activities with temporal and spatial changes taking place. For that purpose, a baseline survey on the geological, climatic, hydrological conditions together with other environmental characteristics of the district were reviewed. Remote Sensing and GIS technologies were applied to produce necessary analysis. Stakeholders meetings were organized to share the findings of the study in a visually appealing way (Tanik A. et al., 2008) (Figure 21Figure 22).

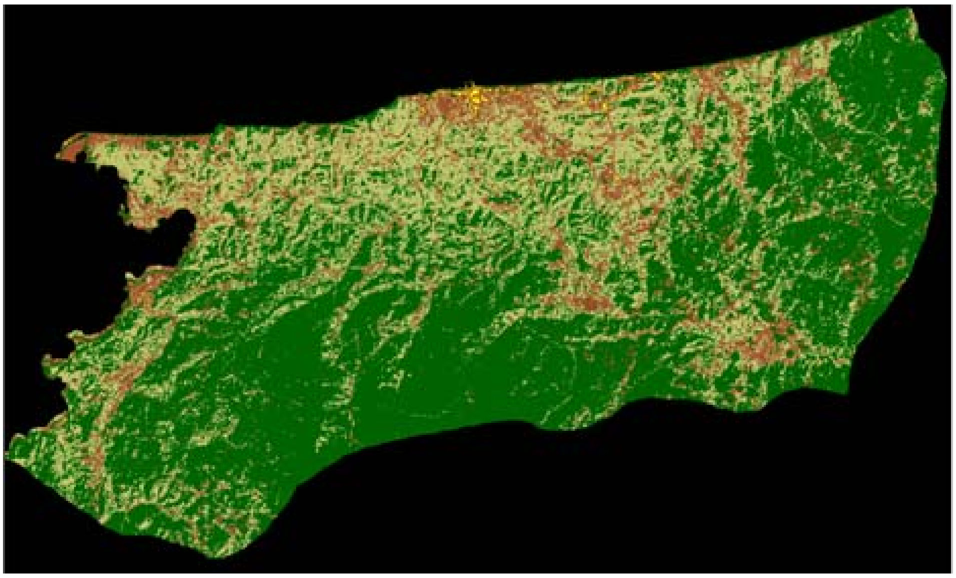

Figure 21 Landuse of Akçakoca in 1987

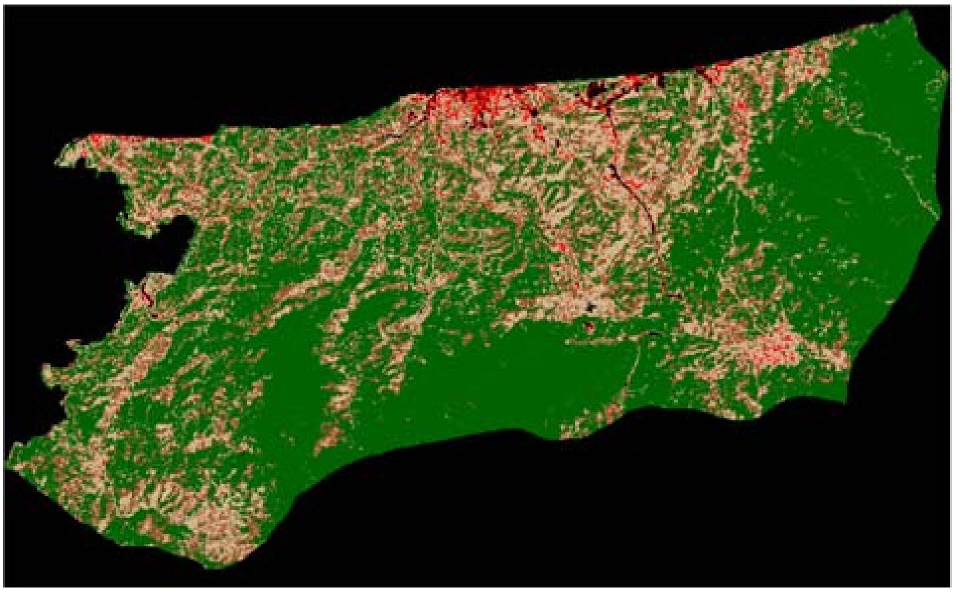

Figure 22 Landuse of Akçakoca in 2006

Land-use (in ha)	**Year**	
	1987	**2006**
Forestry	20,718.3	21,222.7
Agriculture	3,946.3	5,715.6
Meadows & Pasture	10,336.7	7,480.4
Settlement	72.9	655.5
Total	35,074.2	35,074.2

Tskaltsminda, Georgia

A pilot ICZM project at Tskaltsminda coastal community employed the generated sets of GIS data, which included vulnerability zones for flora and fauna, habitat types, land use and cadastral layers; based on which the functional zoning was derived integrating current uses and proposed management regimes for the area. Remote sensing and GIS tools served to visualise the coastal assets, conflicts and potential solutions for the community.

The intention of the local planning project was to verify assumptions about weakness in coastal management, conservation challenges and possible solutions proposed in the national ICZM strategy for Georgia(ECBSea, 2009) (Figure 23 Figure 24).

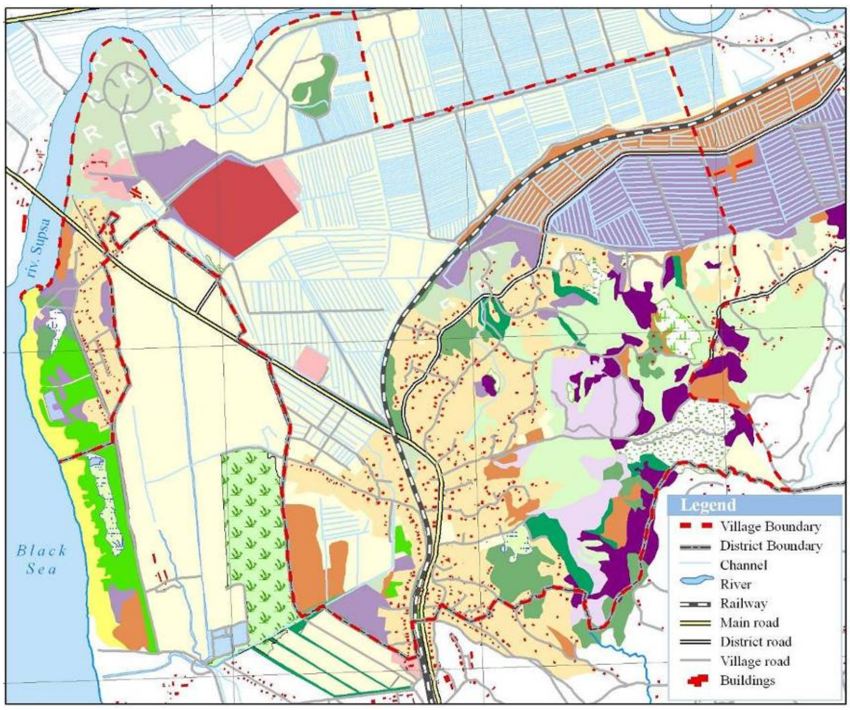

Figure 23 Habitat Types in Tskaltsminda area

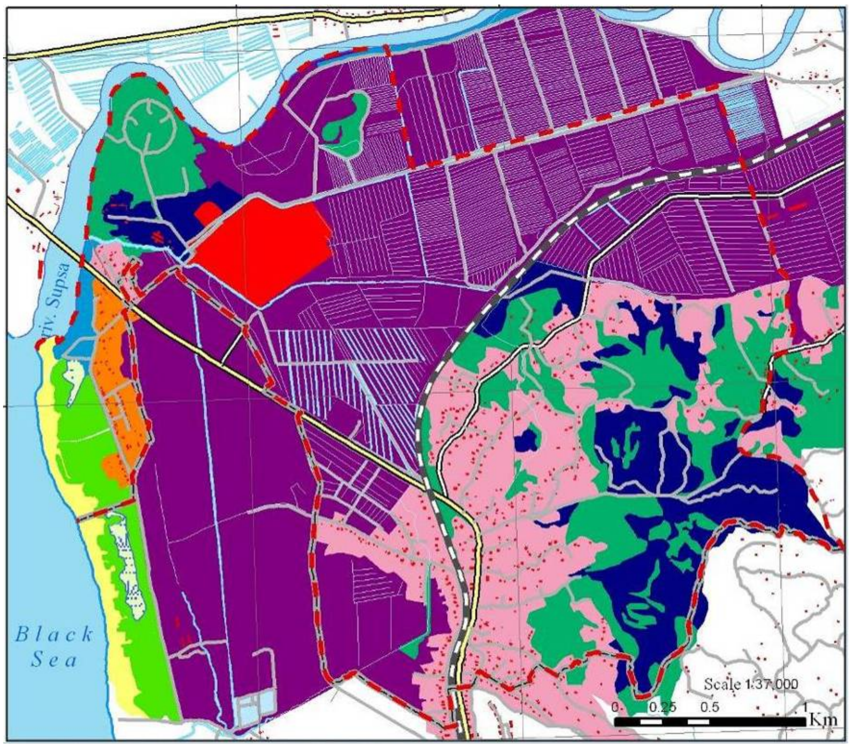

Figure 24 Functional Zoning

Kilyos, Turkey

In Kilyos, the length of the coastline was determined, as it is important for coastal zone management applications such as shoreline classification, monitoring erosion, mapping biodiversity, and for the planning and control to nature and manmade disasters. Monitoring temporal coastal changes is using remote sensing data and GIS helps find solutions to the potential environmental problems on time. Furthermore, accurate, fast and low cost data/information can be obtained in the studies aimed at determining the potentials in hydrological and environmental changes and updating relevant information (Seker D.Z. and C. Goksel, 2003)

The aim of the study is to identify the changes of coastal sand dunes of Kilyos region (the northern part of Istanbul, Black Sea Coast) due to natural and human induced (urbanization, agricultural and mining activities, and etc.) effects (wind and wave) by multitemporal satellite images and GIS technology (Dogru et al., 2006) Figure 25 is shown the result of the study.

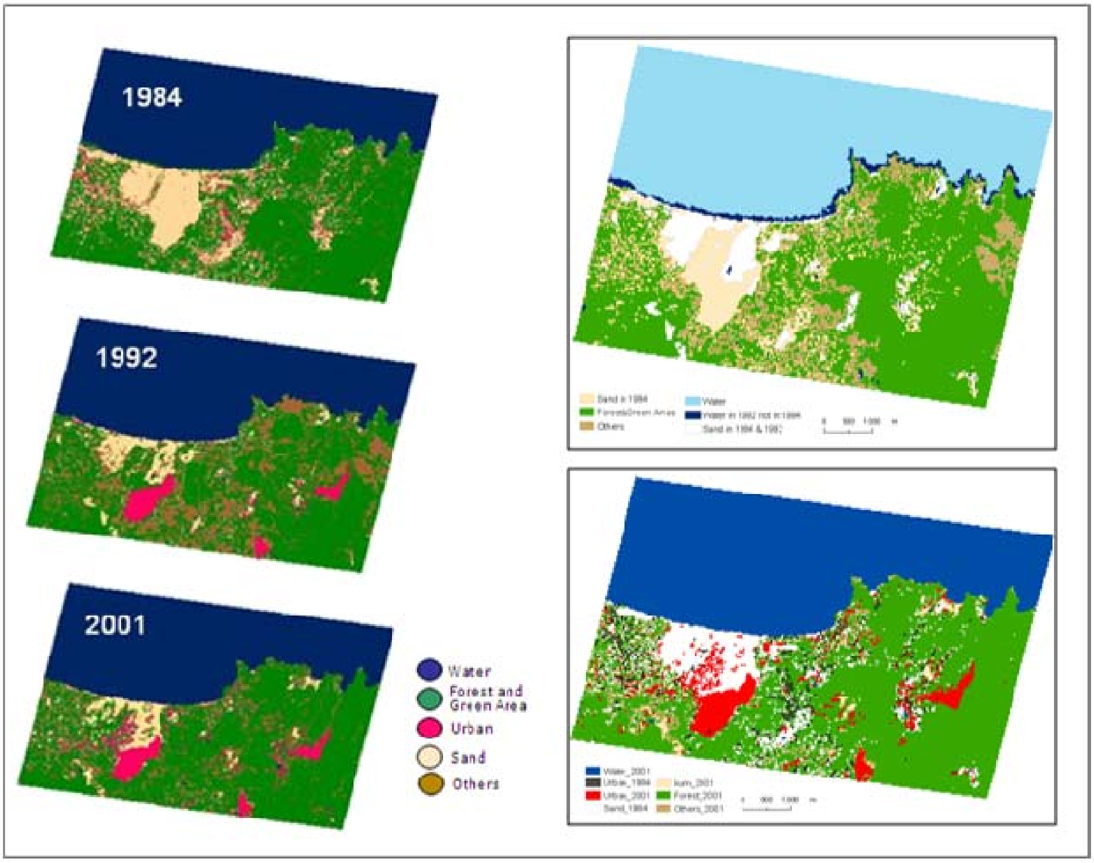

Figure 25 Classification result of 1984, 1992 and 2001 dated Landsat Images and GIS analysis to present the change detection in the sensitive region.

Coastal sensitivity maps, Black Sea

The regional contingency plan for oil spill emergency response, see (BSERP, 2004), contain coastal sensitivity and risk assessment index maps showing shoreline classification, as well as sensitive biological and human-use resources against possible sources and overall risk from oil pollution.

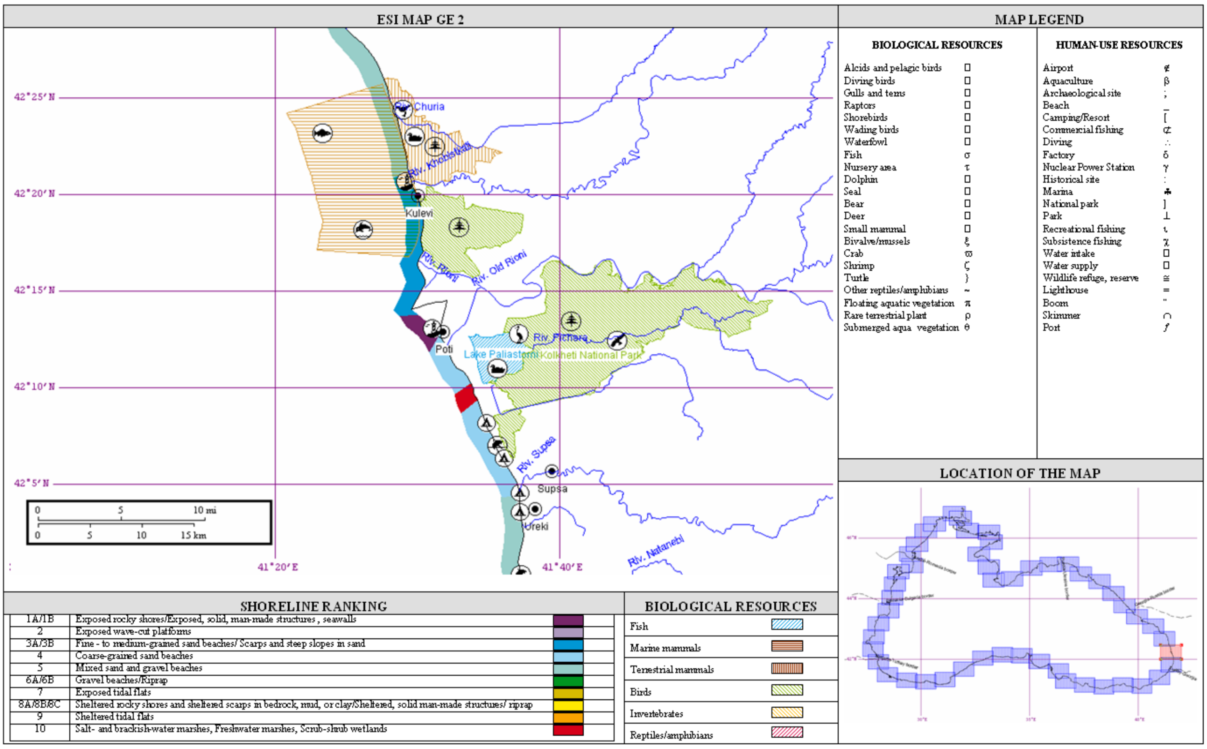

Figure 26 Oil spill coastal sensitivity maps for the Black Sea area

FP7 PEGASO

It should be mentioned in the context of ICZM that forthcoming large-scale integrating collaborative project PEGASO (2009) is under consideration by the European Commission's 7th Framework Programme (FP7). PEGASO will be coordinated by the Universitat Autònoma de Barcelona (UAB). The aim of PEGASO is to build on existing capacities and develop common novel approaches to support integrated policies for the coastal, marine and maritime realms of the Mediterranean and Black Sea Basins in ways that are consistent with and relevant to the implementation of the ICZM Protocol for the Mediterranean. One of the objectives of PEGASO is to refine and further develop efficient and easy to use tools, including progress indicators, for making sustainability assessments in the coastal zone.

EnviroGRIDS and PEGASO share a common vision through participation of several important partners (UAB, GRID/University of Geneva, Danube Delta National Institute, Black Sea Commission and its subsidiary bodies). These two projects hold substantial capacity to streamline the research in developing spatially explicit sustainability indicators and derive harmonized indicator subsets visualizing vulnerabilities across the river basins and the coastal zones of the Southern European and the Black Sea countries (Lehmann A. et al., 2009).

4 Data requirements for hydrological modelling

Soil Water Assessment Tool (SWAT) is used for hydrological modelling in EnviroGRIDS. SWAT is a program used for hydrologic simulations at various scales. This watershed-scale program performs simulations that integrate various processes such as hydrology, climate, chemical transport, soil erosion, pesticide dynamics, and agricultural management. SWAT accounts for variable soil and land cover conditions by subdividing the simulated catchment into sub-areas. The model uses a daily to sub-hourly time step, and can perform continuous simulation for a 1- to 100-year period. SWAT has an ArcGIS (product of ESRI) interface, which takes layers of information such as soil, land cover, elevation, land management as inputs, and calculates hydrology, erosion, and chemical transport both inland and in-stream as outputs.

Tasks of data collection for SWAT, hydrological model building, calibration, validation, assessment of uncertainties, as well as driving model under different scenarios, belongs to WP4. For the simulation of processes at catchment level, SWAT requires data on DEM, soil, land cover, and climate for model setup, and river discharges, river water quality, and crop yield (as available) for calibration and uncertainty analysis. Most of this data is available from the Internet including the remote sensing data, which shall be obtained in collaboration with WP2.

4.1 Digital Elevation Model

ASTER GDEM

ASTER Global Digital Elevation Model is the product of the collaboration of The Ministry of Economy, Trade and Industry of Japan (METI) and the National Aeronautics and Space Administration (NASA).

This DEM is acquired by a satellite-borne sensor "ASTER" covering all the land on Earth at a resolution of 30 meters.

The distribution started on June 29th 2009 and is freely accessible via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan and from NASA's Land Processes Distributed Archive Center (LP DAAC):

http://www.gdem.aster.ersdac.or.jp/index.jsp

https://igskmncnwb001.cr.usgs.gov/aster/afd/index.php

SRTM

The Shuttle Radar Topography Mission (SRTM) is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and NASA (http://www2.jpl.nasa.gov/srtm/index.html).

SRTM obtained elevation data on a near-global scale to generate the complete high-resolution digital topographic database of Earth (SRTM represented the best resolution global DEM until most recent development and public distribution of higher resolution global coverage with GDEM project, see above). SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

The SRTM radar contained two types of antenna panels, C-band and X-band. Data from the X-band radar are used to create slightly higher resolution DEMs but without the global coverage of the C-band radar. The SRTM X-band radar data are being processed and distributed by the German Aerospace Center, DLR (http://www.dlr.de).

Virtually the entire land surface between +/- 60 degrees latitude was mapped by SRTM (Black Sea Catchment entirely falls with this range). Processing of the C-band data was useful to generate and release derived products (shaded relief, perspective views, anaglyphs, etc.) produced from DEMs.

SRTM can still be useful in SWAT test runs and applications complementing higher resolution GDEM product.

DEM, Soil, and Land Use Resolution Effects

Spatial resolution of SWAT input data such as DEM, Soil, and Land Use have critical influence on hydrological modelling and therefore an intimate understanding of model behavior against changes in data resolution is an important factor. Several papers analyze variability on data resolution for catchment of various dimensions (see review article by (Bosch et al., 2004; Gassman et al., 2007)) and found that SWAT streamflow estimates for a 22.1 km^2 subwatershed of the Little River watershed in Georgia were more accurate using high resolution topographic, land use, and soil data versus low resolution data obtained from BASINS model of US Environmental Protection Agency (http://www.epa.gov/waterscience/basins). (Cotter A. S. et al., 2003) report that DEM resolution was the most critical input for a SWAT simulation of the 18.9 km2 Moores Creek watershed in Arkansas, and provide minimum DEM, land use, and soil resolution recommendations to obtain accurate flow, sediment, nitrate, and total P estimates. (Di Luzio et al., 2005) also found that DEM resolution was the most critical for SWAT simulations of the 21.3 km2 Goodwin Creek watershed in Mississippi; land use resolution effects were also significant, but the resolution of soil inputs was not. (Chaplot, 2005) found that SWAT surface runoff estimates were sensitive to DEM mesh size, and that nitrate and sediment predictions were sensitive to both the choice of DEM and soil map resolution, for the Walnut Creek watershed in central Iowa. However, the most accurate results did not occur for the finest DEM mesh sizes, contrary to expectations.

4.2 Land Cover Classification Systems (MODIS, MERIS)

As indicated above, ArcSWAT extension provides for automated LUT-type input from the following land cover classifications systems: USGS LULC and US EPA's NLCD 1992 or NCDL 2001 (2006 input is pending), while user is allowed to create look up table to convert its land cover into SWAT input.

Available 'open source' moderate/medium resolution imagery such as MODIS (Terra and Aqua) and MERIS are processed to derive standard science products including raster land covers. These products are based on a range of classification systems outlined below.

MODIS: [4]

MODIS Land Cover Type product (named MCD12Q1) contains multiple classification schemes, which describe land cover properties derived from observations spanning a yearly inputs of Terra and Aqua covering 2001-2007 period. The primary land cover scheme identifies 17 land cover classes defined by the International Geosphere Biosphere Programme (IGBP), which includes 11 natural vegetation classes, three developed and mosaiced land classes, and three non-vegetated land classes. The MODIS Land Cover Product is produced at 500-m spatial resolution. This scale is the finest that is practically achievable with the MODIS instrument. Although the MODIS land bands are imaged at 250- and 500-m spatial resolution, these are nominal values for nadir pixels.

The MODIS Terra + Aqua Combined Land Cover Type Yearly L3 Global 500 m SIN Grid science product incorporates, in particular, five different land cover classification schemes, derived through a supervised decision-tree classification method:

- Land Cover Type 1: IGBP global vegetation classification scheme
- Land Cover Type 2: University of Maryland (UMD) scheme
- Land Cover Type 3: MODIS-derived LAI/fPAR scheme
- Land Cover Type 4: MODIS-derived Net Primary Production (NPP) scheme
- Land Cover Type 5: Plant Functional Type (PFT) scheme

The land product MCD12Q1 in its first five 'bands' contain as feature class attributed layers above 5 classification schemes. Standard symbology can be applied to each class layer to display any of the classification land covers in a standard and user friendly colour scheme/legend.

[4] Source of MODIS information is Strahler, A., Muchoney, D., Borak, J., Friedl, M., Gopal, S., Lambin, E., and Moody, A., 1999, MODIS Land Cover Product Algorithm, *in* Theoretical Basis Document (ATBD), V., ed.

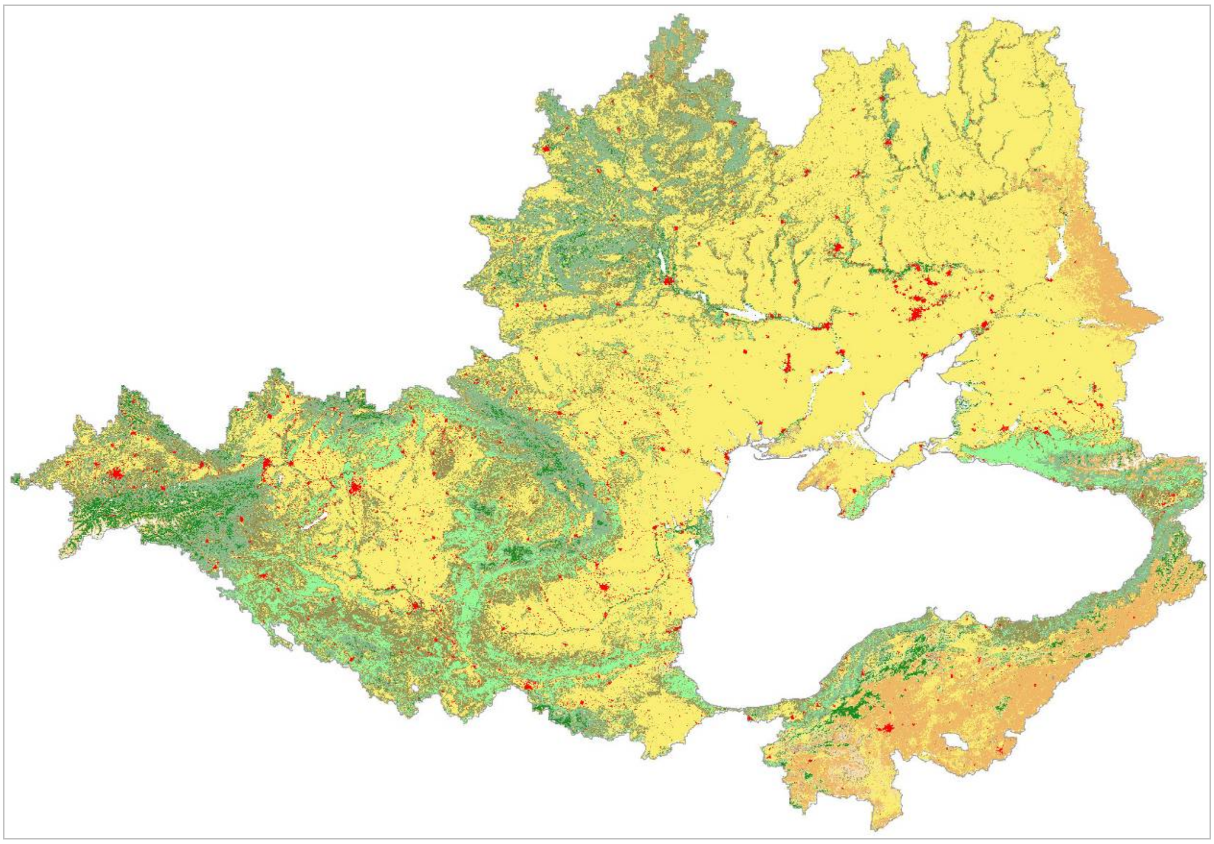

Figure 27 MODIS land cover science product (MCD12Q1) @ Black Sea Catchment (2007)

Table 5 below provides description of each class attribute, respective colour code and definition of the classification types for each scheme.

Table 5 MODIS Land Cover Type product (MCD12Q1), class attribute description

Class	IGBP (Type 1)	UMD (Type 2)	LAI / fPAR (Type 3)	NPP (Type 4)	PFT (Type 5)
0	Water	Water	Water	Water	Water
1	Evergreen Needle-leaf forest	Evergreen Needle-leaf forest	Grasses/Cereal crops	Evergreen Needle-leaf vegetation	Evergreen Needle-leaf trees
2	Evergreen Broad-leaf forest	Evergreen Broadleaf forest	Shrubs	Evergreen Broadleaf vegetation	Evergreen Broad-leaf trees
3	Deciduous Needle-leaf forest	Deciduous Needle-leaf forest	Broad-leaf crops	Deciduous Needle-leaf vegetation	Deciduous Needle-leaf trees
4	Deciduous Broad-leaf forest	Deciduous Broad-leaf forest	Savannas	Deciduous Broad-leaf vegetation	Deciduous Broad-leaf trees
5	Mixed forest	Mixed forest	Evergreen Broad-leaf forest	Annual Broad-leaf vegetation	Shrub
6	Closed shrublands	Closed shrublands	Deciduous Needle-leaf forest	Annual grass vegetation	Grass
7	Open shrublands	Open shrublands	Evergreen Needle-leaf forest	Non-vegetated land	Cereal crops
8	Woody savannas	Woody savannas	Deciduous Needle-leaf forest	Urban	Broad-leaf crops
9	Savannas	Savannas	Non-vegetated		Urban and built-up
10	Grasslands	Grasslands	Urban		Snow and ice
11	Permanent wetlands				Barren or sparse vegetation
12	Croplands	Croplands			
13	Urban and built-up	Urban and built-up			
14	Cropland/Natural vegetation mosaic				
15	Permanent snow and ice				
16	Barren or sparsely vegetated	Barren or sparsely vegetated			

MERIS: [5]

ESA's Globcover project produce land cover mapping using 300m time series acquired with MERIS instrument. The Globcover products are freely available and include:

- The Globcover Land Cover map for the period December 2004 - June 2006 (1 product). This global Land Cover map is derived by an automatic and regionally-tuned classification of a MERIS FR time series. Its 22 land cover classes are defined with the UN Land Cover Classification System (LCCS). Global land classification and colour scheme (in RGB) is provided in the Table 6 below.
- The regional Globcover Land Cover maps for the period December 2004 - June 2006 (11 products). This set of regional land cover maps are also derived by the same automatic and regionally-tuned classification of a MERIS FR time series. However, the land cover typology has been extended to 51 possible land cover classes consistently discriminated only at the continental scale.

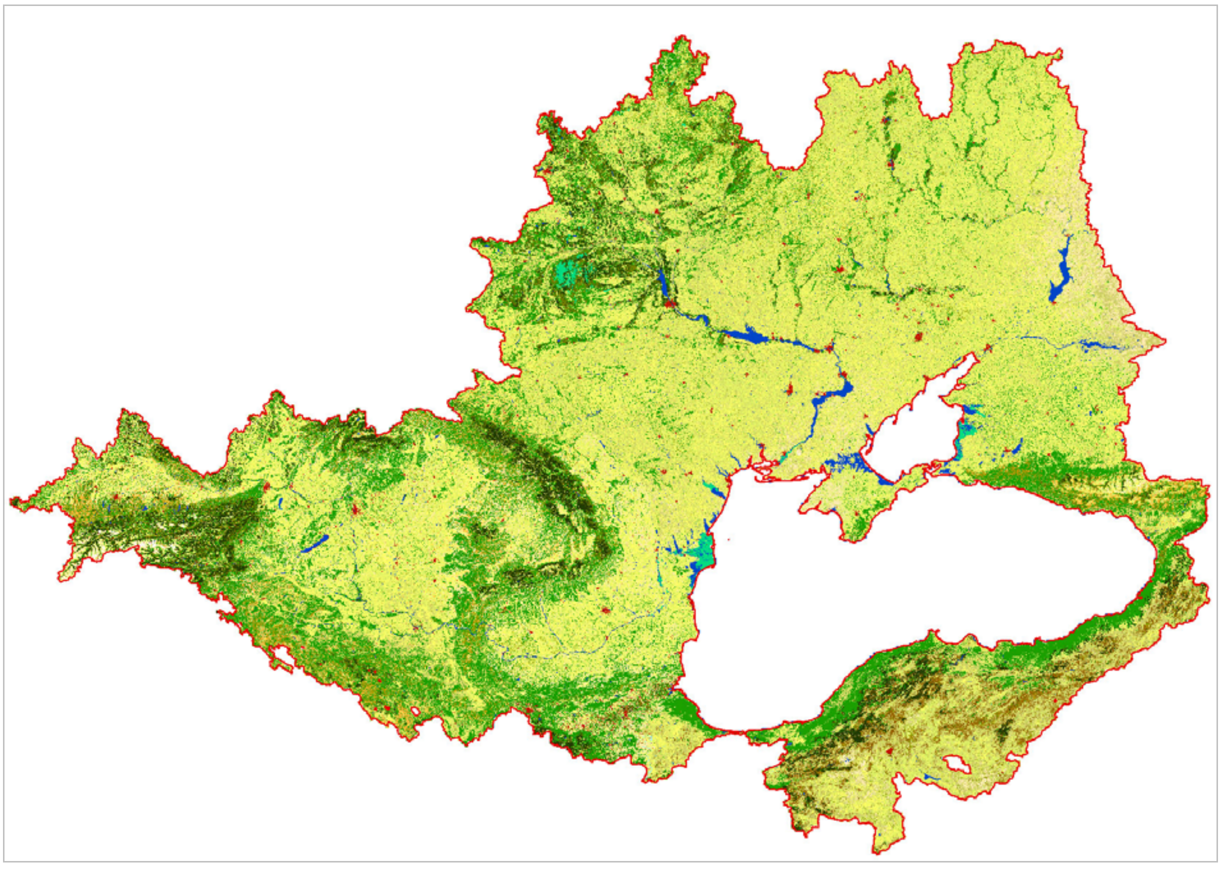

Figure 28 MERIS Globcover product @ Black Sea Catchment (2004-2006)

[5] Source of MERIS information is Bicheron P., Defourny P., Brockmann C, Schouten L., Vancutsem C, Huc M., Bontemps S., Leroy M., Achard F., Herold M., Ranera F., and O., A., 2008, GLOBCOVER: Products Description and Validation Report.

Table 6 Globcover, class attribute description

Value	Label	Red	Green	Blue
11	Post-flooding or irrigated croplands (or aquatic)	170	240	240
14	Rainfed croplands	255	255	100
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	220	240	100
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	205	205	102
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	0	100	0
50	Closed (>40%) broadleaved deciduous forest (>5m)	0	160	0
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	170	200	0
70	Closed (>40%) needleleaved evergreen forest (>5m)	0	60	0
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	40	100	0
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	120	130	0
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	140	160	0
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	190	150	0
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	150	100	0
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	255	180	50
150	Sparse (<15%) vegetation	255	235	175
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	0	150	120
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	0	220	130
190	Artificial surfaces and associated areas (Urban areas >50%)	195	20	0
200	Bare areas	255	245	215
210	Water bodies	0	70	200
220	Permanent snow and ice	255	255	255
230	No data (burnt areas, clouds,…)	0	0	0

See annex "G. Accessing Land Cover Products @ BSC (MODIS & MERIS)" to get a full description of downloading procedure.

4.3 Soil moisture

Soil moisture product could be an interesting input for hydrological model. Therefore we might consider using them in SWAT modeling and calibration.

ERS/MetOp Soil Moisture (http://www.ipf.tuwien.ac.at/radar/index.php?go=ascat):

The Institute of photogrammetry and remote sensing at Vienna University of Technology propose soil moisture observations derived from radar backscattering signal acquired with scatterometers onboard the satellites ERS-1 and ERS-2 and MetOp satellites. They offer two global products, from 1992 to present, at a coarse resolution of 25-50 kilometers:

Description of the products

- Level 2 products representing the soil moisture content within a thin soil surface layer (< 2 cm) during the time of overflight of the satellite. Surface Soil Moisture (SSM) available on a weekly basis.
- Level 3 products representing the water content in the soil profile, regularly sampled in space and time. Soil water index (SWI) available on a monthly basis.

One of their research activities are precisely highlighting excessive drought conditions in Black Sea watershed catchment, in summer 2007 (Figure 27).

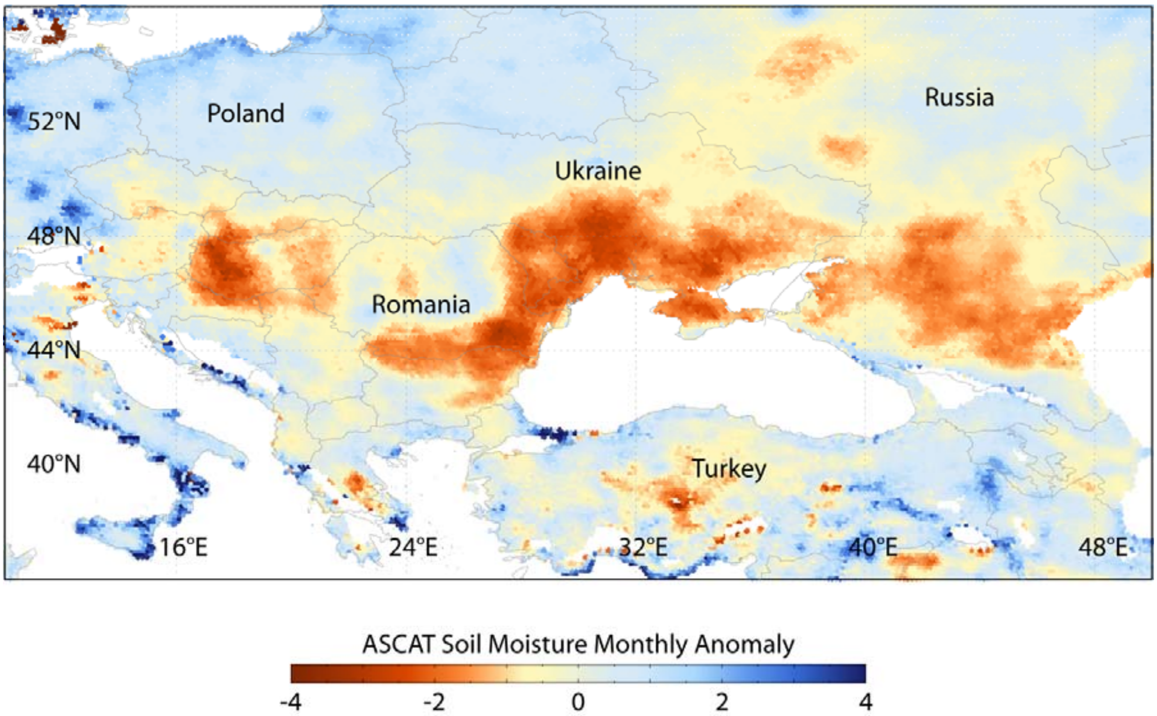

Figure 29 Surface soil moisture anomaly at Black Sea Catchment in Summer 2007

"This figure shows the as indicated by an ASCAT surface soil moisture anomaly calculated as the quotient between the departure from the long term mean for that day of the year and the standard deviation of the same long-term mean. The anomalous area comprises parts of Hungary, Romania, Moldova and Ukraine. Indeed, the heat wave and lack of precipitation caused 500 deaths in Hungary (source: Associated Press) whereas the drought in Moldova was the most severe in living memory, with average cereal production down 70% of the previous five years (source: FAO). The Ukrainian poor wheat crops contributed to the soaring global wheat prices later that year (source: BMI)."

4.4 Meteorological data

Remote sensing meteorological data have been requested for WP4, WP5 and WP6.

- Rainfall maps (measured or forecasted rainfall)
- Wind speed
- Evapotranspiration
- Solar radiation
- Relative humidity

They will be specially needed for:

Task 4.2 which will do SWAT calibration

Task 5.6 which will take charge of flood early warning and flood risk assessment at large scale

Task 6.3 which will develop a Black Sea Basin observation system for citizens and some case studies on floods in Ukraine, Danube Delta, together with DHMO (small scale, high resolution imagery).

Rather real-time images are needed, but we could provide them with archives for initial development and tests.

Some Data Source References:

Precipitations (from GPCC)	http://gpcc.dwd.de
WorldClim database	http://www.worldclim.org
CRU Database	http://www.cru.uea.ac.uk/cru/data
Dartmouth Flood Observatory	http://www.dartmouth.edu/~floods
TRMM / TOVAS (TRMM Online and Visualization and Analysis System	http://disc2.nascom.nasa.gov/Giovanni/tovas/
Multi-Sensor Precipitation Estimate (apparently they are not covering whole Black Sea, to be checked directly with EUMETSAT)	http://www.eumetsat.int/
Global data climate sets H08 from Hirabayashi et al. 2008. Rasters with daily values of rainfall and others worldwide from 1948-2006. Discharge values - freely available - of the main rivers in the world	http://www.bafg.de/GRDC/Home/homepage__node.htm

5 GenesiDR (Remote Sensing on the GRID)

GENESI-DR (www.genesi-dr.eu) rasises the challenge to facilitate access to Earth science digital repositories dispersed all over Europe.

This project should allow European and world-wide science users to locate, access, combine and integrate historical and fresh harmonized and standardized Earth data originating from space, airborne and in-situ sensors.

5.1 GENESI-DR Dataset Discovery

This web service allows (Figure 30) dynamic research products available within digital repositories registered in GENESI-DR. By coarsely defining the extent of the Black Sea watershed catchment, presently a list of 55 records in land, atmosphere and marine domains should be available.

- ASAR (Advanced Synthetic Aperture Radar) products http://envisat.esa.int/instruments/asar/
- MERIS images and products: Chlorophyll concentration, GlobCover, Global Vegetation Index, terrestrial Chlorophyll Index…
- AATSR (Advanced Along Track Scanning Radiometers): Average Surface Temperature…
- SPOT images (1,2,3,4,5)
- GOME (Global Ozone Monitoring Experiment)
- OMI (Ozone Monitoring Instrument): Ozone products, tropospheric column densities for NO2
- NDACC (Network for the Detection of Atmospheric Composition Change) – Lidar
- SRTM (Shuttle Radar Topography Mission)
- SWACI (Space Weather Application Center Ionosphere)
- GLOBmodel temperature
- SST (Sea Surface Temperature)

Following the previous list of available data in GENESI-DR repository various usage scenarios of data could be imagined. For instance:

- coastal pollution (Chlorophyll concentration, sea surface temperature),
- deforestation (vegetation indices),
- land cover changes (MODIS land cover products) could be highlighted by implementing a change detection algorithm on the GRID-SDI infrastructure, using available near real-time products mentioned above, and then extracting differences on a meaningful frequency (weekly, monthly, seasonally, annually basis) according to the frequency of product availability.

These analyses (map, report, and statistics) could be then redistributed via web services to the entire EG community.

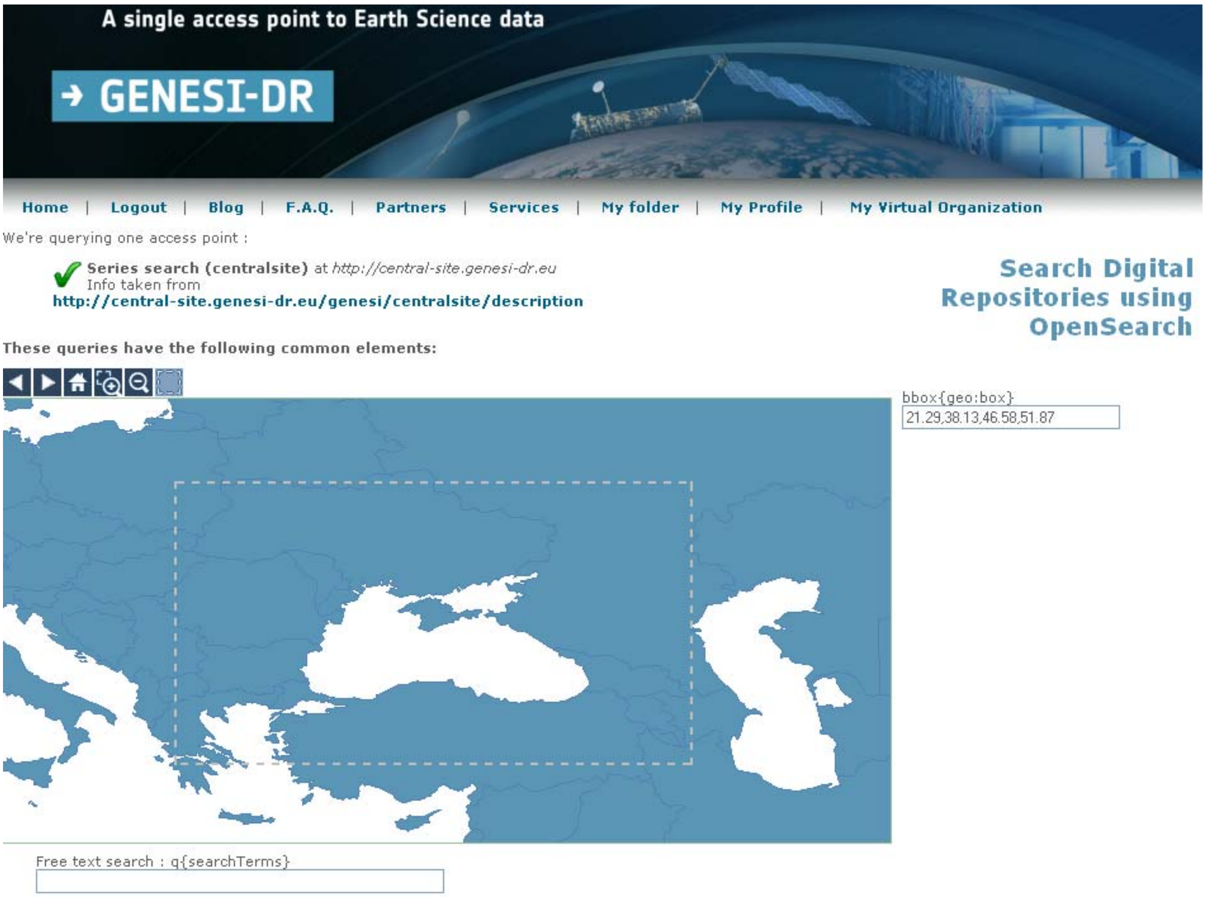

Figure 30 GENESI-DR Dataset Discovery web interface

5.2 GENESI-DR & EnviroGRIDS MOU

A MoU between EnviroGRIDS and GENESI-DR has been signed. This collaboration will improve data access to the EnviroGRIDS community. Reciprocally new data/products/services developed within the project will become available to authorized GENESI-DR users. To make such exchanges possible, the two infrastructures will be fully interoperable.

The specific goals of the collaboration are:

- To enable the EnviroGRIDS community to discover/access and use data and services available in Digital Repositories federated to GENESI-DR.
- To validate GENESI-DR infrastructure with Earth Science (ES) application scenario (e.g. EnviroGRIDS SDI to query GENESI-DR data in order to retrieve data to run SWAT model).
- To federate in GENESI-DR new Digital Repositories (Sensor Data as well as Base Layers to run SWAT) that are linked to EnviroGRIDS.
- To execute SWAT model with data provided by the federated GENESI-DR including the new Digital Repositories that are linked to EnviroGRIDS.

6 EnviroGRIDS case studies and demonstration products

Here are some examples envisaged case studies and possible demonstration outputs envisaged by UNIGE, ITU and GeoGraphic partners within the EnviroGRIDS framework.

At this first stage we mainly propose visual products hoping that it may reach a wider audience. We hope highlighting sensitive issues to the general public, education as well as governments and nongovernmental organizations in order to raise environmental awareness in this region.

Such work presented below could lead to expositions, article in local magazines and educational materials (atlas, training courses…).

6.1 Igneada (Turkey)(ITU, WP5)

Igneada; Remote Sensing of Sensitive Area: A Case Study of Igneada-Turkey

Igneada is one of the most important sensitive areas of Turkey at the Black Sea Coast. This region is a complex of seasonally flooded forests, wetlands, freshwater lakes and sand dune habitats on the Black Sea coast. Rich biodiversity of the region is very important for ecological balance of Turkey and the Black Sea Region. It is one of the largest protected and wildlife management areas on the Black Sea coast (2,500 ha). Because of this reason this sensitive region must be conserved, managed and developed. Igneada is located at 41° 51 ΄ N and 27 ° 57 ΄ E (Figure 32).

Figure 31 Igneada Region (Turkey)

Igneada is one of the Important Birds Areas (IBAs). Igneada bottomland forests support a breeding population of *Ciconia nigra* and a high number of *C. ciconia* and other migratory raptors. Igneada and its vicinity are rich in fauna due to abundant fresh water habitats. The area provides suitable habitats for feeding and dwelling of the amphibian and reptile species. All existing biodiversity information will be gathered from Igneada forest, and Turkey's Black Sea coast. Several regional indicator species will contribute to the overall list of Black Sea indicator species.

High and medium spatial resolution satellite images will be used to extract land use and land cover information especially vegetation types with the help of detailed field study. At the first stage, satellite images will be processed to eliminate systematic errors and to minimize contamination effects of atmospheric particles by applying radiometric and atmospheric correction. Geometrically corrected satellite data will be classified by using supervised classification technique to get land cover and land use in the region. This step is very important for sustainable management of the biodiversity in the area.

The current national policies on management of biodiversity will be analyze and the links and gaps in the priorities set for the biodiversity issue will be determine as a whole and also for the selected region.

6.2 West Stara Planina (Bulgaria and Serbia)(WP3 task 3.3)

The mountain area ¨West Stara Planina¨ shared between North-west Bulgaria and South-east Serbia is cited as one of the most depopulated areas in Europe after the Second World War. These depopulation processed have been accompanies by some highest rates of land abandonment (around 30%). and consequent natural succession of shrublands and even forest.

6.3 Rioni river basin (Georgia) (Geographic, WP2)

Case studies using medium to high resolution data from eastern Black Sea region, where the land cover change detection and remote sensing could be of important to document the sustainability conditions (Figure 32 Figure 33).

The Rioni river is the largest one in western Georgia with the length of approximately 330 km and catchment area of some 13,400 Km^2. Tributaries of Rioni mainly flow from mountainous areas: the right tributaries Lukhumi, Tskhenistskali and Tekhuri drain from the southern slopes of the Great Caucasus Range, while left tributaries Kvirila, Dzirula and Khanistskali have their sources at Lesser Caucasus Range. Glaciers contribute significantly as over 2 million cub. m of ice is estimated to be accumulated in Rioni watershed (glacier retreat detection due to climate change and other factors at higher resolution coverage of the Greater Caucasus would be a separate task considered).

Downstream of Kutaisi, the largest town in the river basin with 250 thousand inhabitants (located some 170 km from the source), the river flows on Kolkheti lowland and enters the Black Sea near key port city of Poti with a population of 50 thousand. The population of the entire basin is estimated to exceed 500 thousand.

River flow regimes are controlled by series of reservoirs located both upstream and downstream of Kutaisi. In the lower reaches along the Kolkheti lowland the river is mostly diked with 3-5 m height soil berms. Major flooding events were recorded in every 40-50 years, while relatively small floods are usual phenomena and happen every 4-5 years. Deforestation and inappropriate agricultural practices within the catchment are also the source of concern, leading to slope instabilities, soil erosion and excessive discharges of sediments and pollutants into the Black Sea.

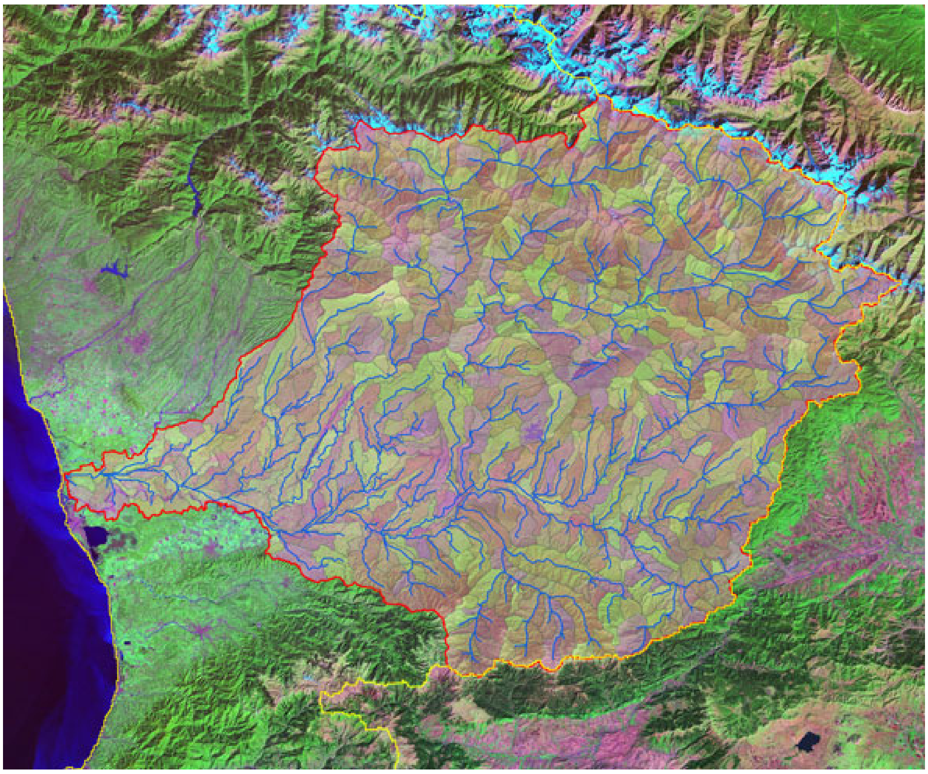

Figure 32 Rioni sub-basins against Landsat backdrop

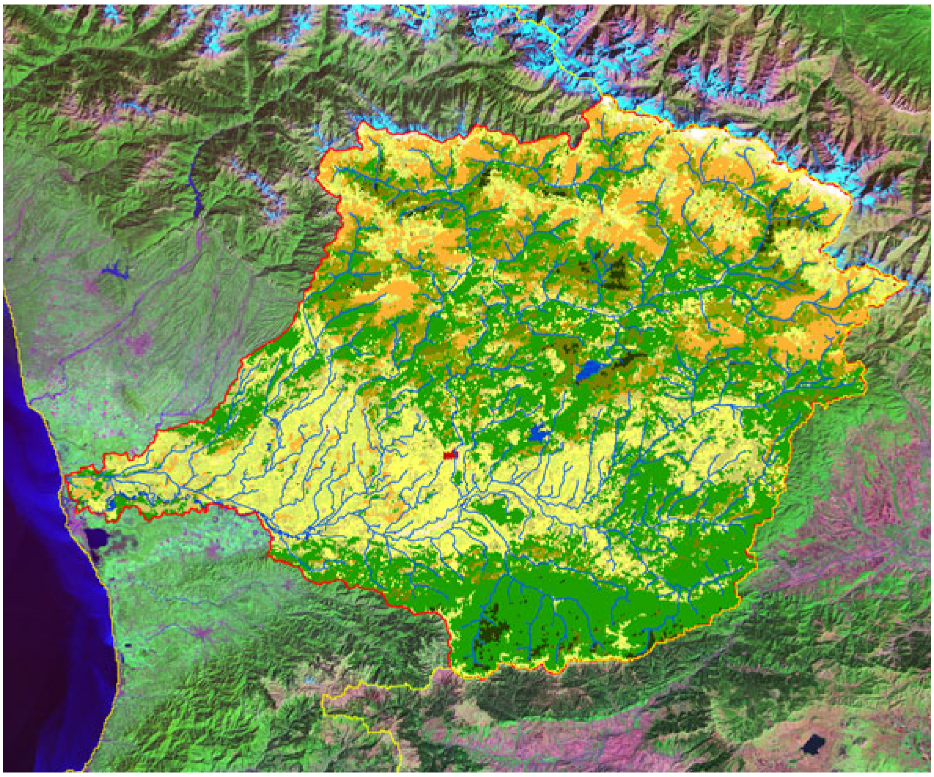

Figure 33 Globcover masked with Rioni catchment

There are several reasons why catchment of the Rioni river could be considered as the test case study for modelling the specific hydrological phenomena taking place in this watershed, but also for resembling essential issues of relevance for the Black Sea Catchment:

- Despite of relatively small size, the Rioni basin is spreading from highest mountain areas mostly fed with glaciers, continues its precipitation fed flows on the lowland and joins the Sea, essentially mimicking the hydrological processes of much larger catchments and rivers elsewhere in the Black Sea Catchment. The river and catchment processes strongly change character from mountainous areas into the coastal lowland. It is worth mentioning that the edge of the Rioni catchment touches the eastern boundary of the Black Sea Catchment.
- The rivers in the Western Caucasus are characterized by high sediment loads which merit specific investigation in terms of the impact on coastal zones and the Sea, by means of coupling remote sensing data on coastal changes with catchment data on land use, soil, vegetation hydrology (including glacier mass balance) and sediment transport (Du, 2002) (Halldórsdóttir and Þorbergsson, 2004)
- Due to relatively small area compared to the Black Sea Catchment the application of remote sensing instruments and testing the sensitivity of SWAT modelling with regard to data from various sensors could be performed before extenting the coverage.
- Deforestation and other types of land cover/use changes are apparent in the watershed and these processes can be detected with remote sensing and coupled with sediment and nutrient loads through SWAT modelling.
- Historic pollution, hydrological and climate data of variable quality is mostly available (Vekua et al., 1997), as well as the results of hydrological modelling with different tools (SOBEK, Arcadis 2002), while precipitation data collection improved recently (see www.NEA.gov.ge).

This case study will allow:

- Understating land cover change on Kolkheti lowland in the downstream coastal parts of the Rioni basin, comparing changes taking place in this area with historical maps from as early as the beginning of the 20th century
- Documenting the land cover dynamics taking place in recent decades (using mostly MODIS, Landsat and Aster).
- Deriving habitat classification scheme for Kolkheti wetlands/peat lands.
- Assessing changes in hydrograph network (drainage, straightening of river and stream meanders) and impact on natural habitats.

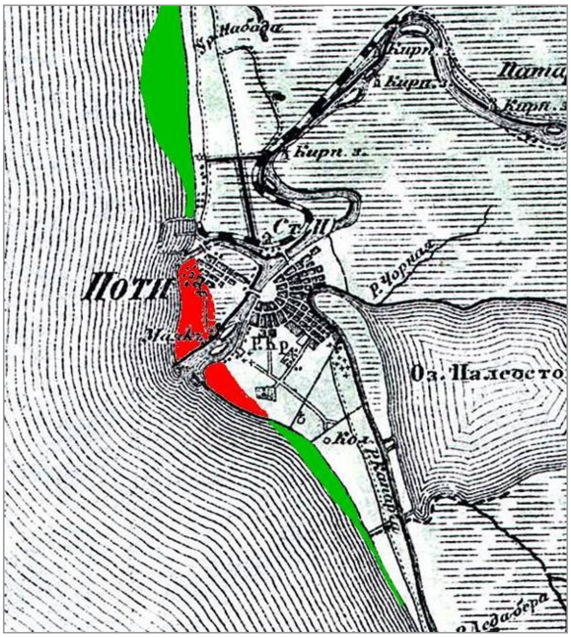

Figure 34 Dramatic shoreline change near Poti, Georgia, against historic map of Rioni delta from 1906

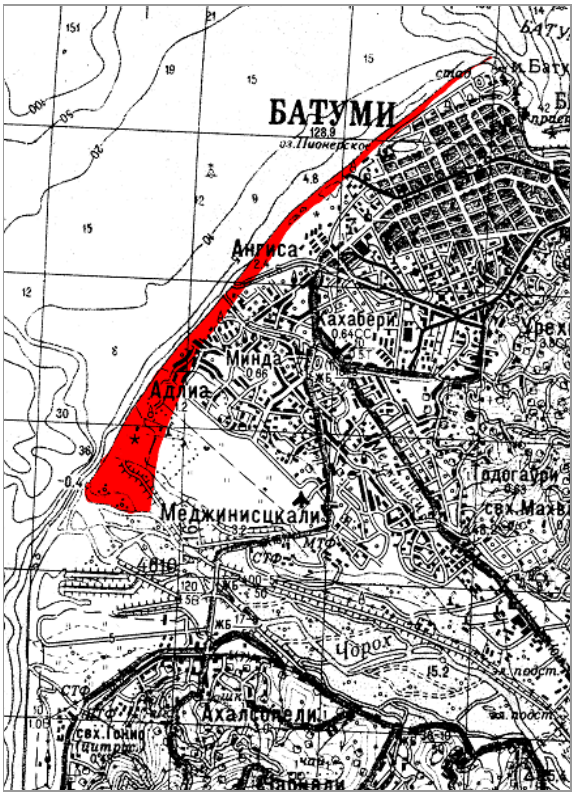

Figure 35 Computer modelling forecast changes of shoreline retreat in Batumi (in red)

Analysis of changes due to variability in sediment transport processes originating from the changes in the watershed and impact on coastal erosion processes for Poti and Batumi municipalities, which would be quantified using higher resolution imagery and aerial photos.

6.4 Atlas from Remote Sensing images

One Planet Many People: Atlas of our Changing Environment has been produced by the United Nations Environment Programme (UNEP, 2005). This very pedagogical product compares spectacular archive satellite images with contemporary one by highlighting thirty years of local and regional changes.

Some examples are presented below which were extracted from the UNEP Atlas (UNEP, 2005): http://na.unep.net/OnePlanetManyPeople/index.php

6.4.1 Ataturk dam, Turkey

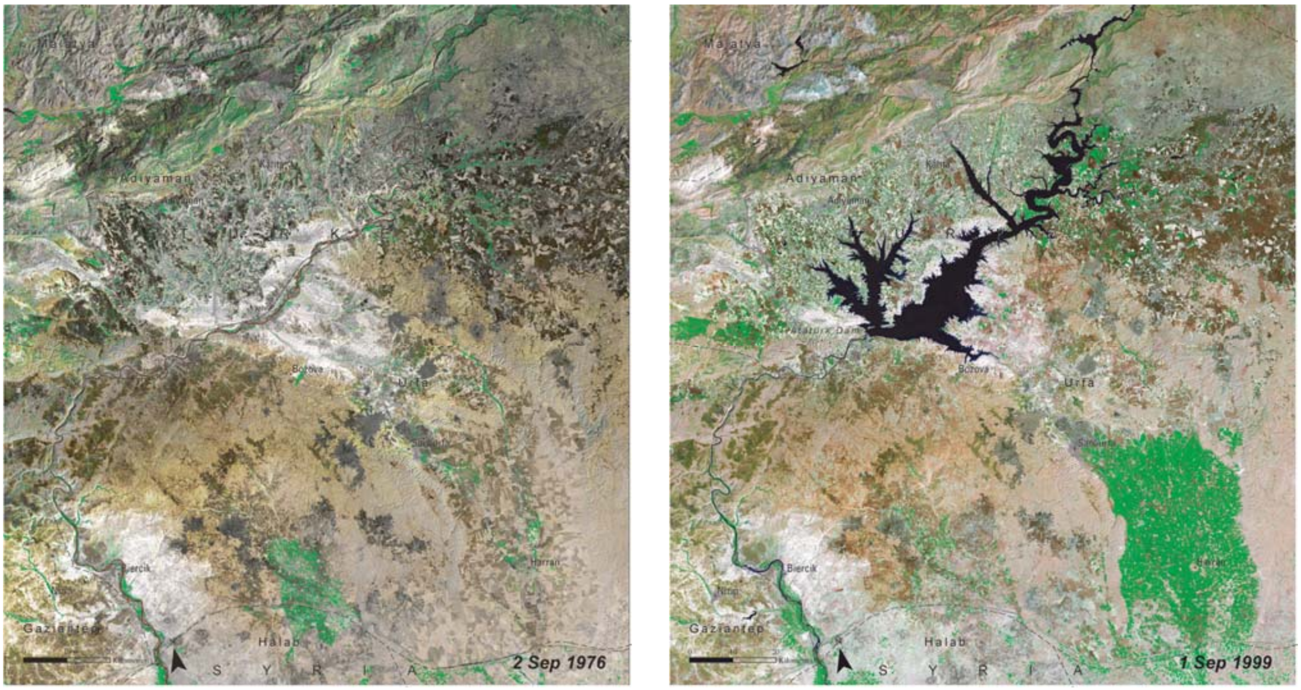

Figure 36 Satellite images of Ataturk dam in Turkey, separated by 23 years

Atatuk dam was built in 1990 on Euphrates River in order to provide irrigation water and electricity to this region. This pairwise image shows this huge hydraulic construction accompanied with the transformation of this arid region into agricultural landscape (Figure 36).

6.4.2 Mesopotamia, Iran-Iraq

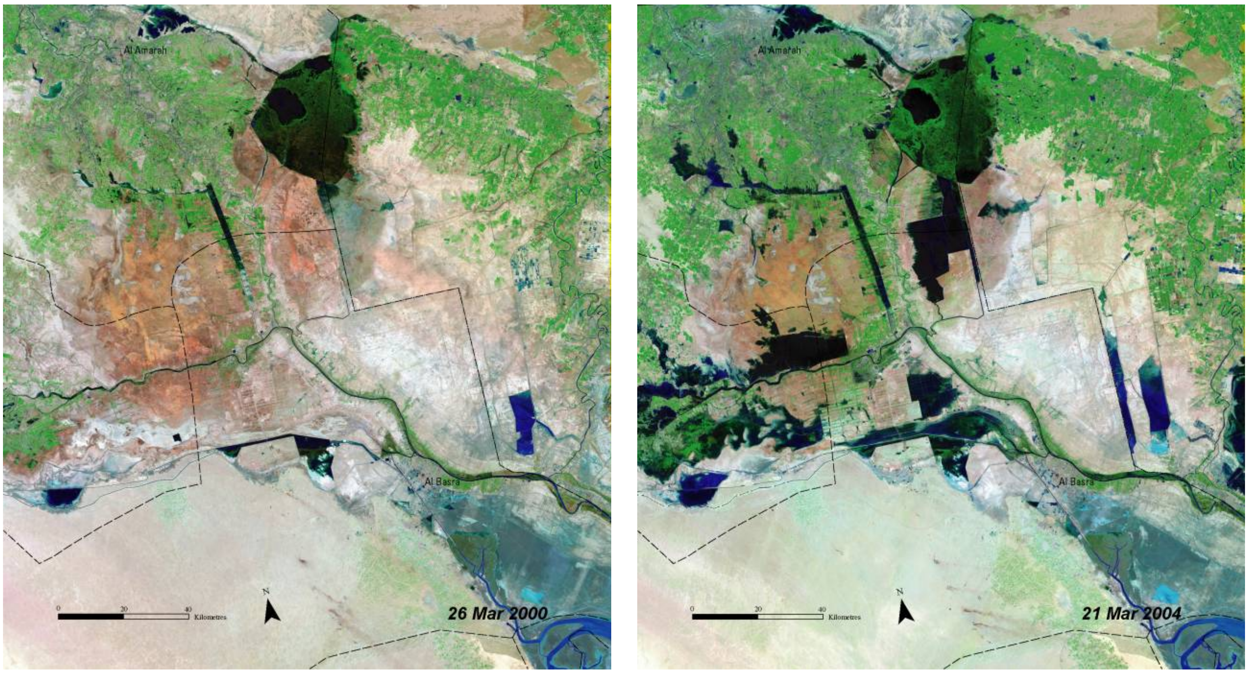

Figure 37 Mesopotamian marshland reflooding and consequently vegetation growth

Located at the confluence of Tigris and Euphrates rivers, Mesopotamian marshland was one of the world's greatest wetlands covering an estimated surface of almost 20'000 km^2. During last decade significantly reduced quantity of water entering the marshes, mainly due to upstream damming as well as drainage activities, leads to the destruction of this ecosystem. Since mid-2003 recovery is in process, the destruction of dykes and drainage canals led to the reflooding of the marshes. Consequently vegetation and wildlife have returned to many parts of the wetlands (Figure 37).

6.4.3 Aral Sea

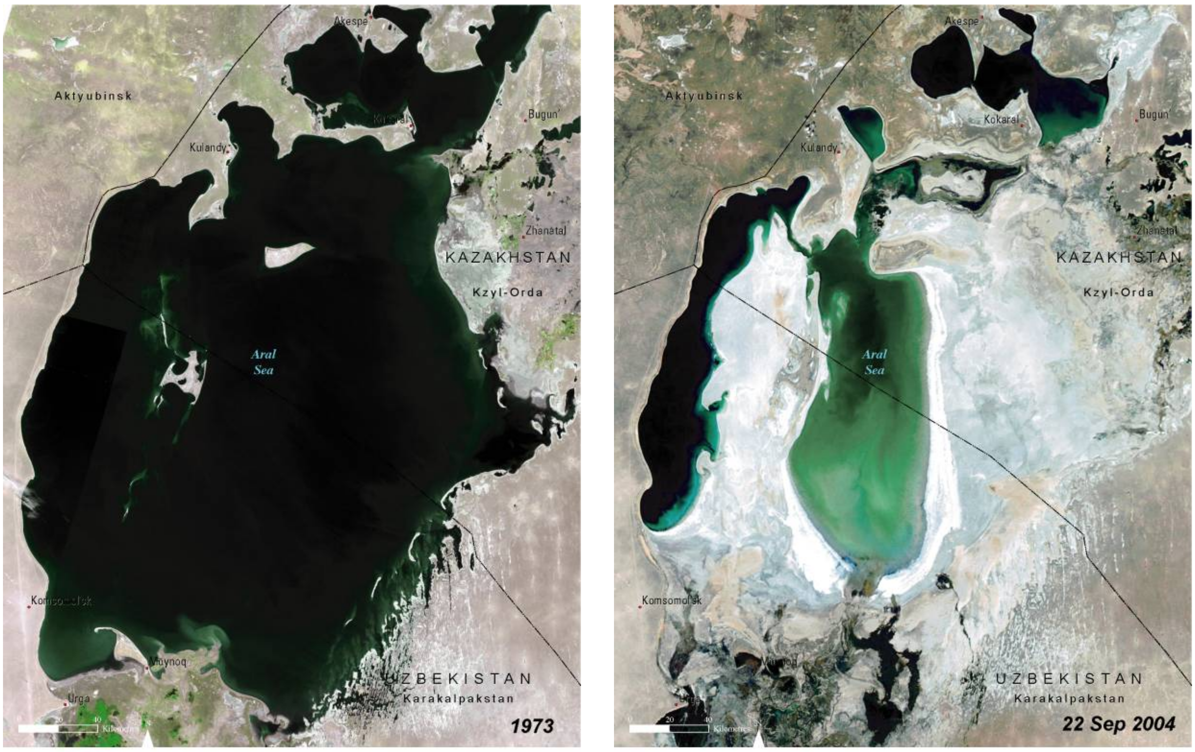

Figure 38 Pairwise satellite images of desertification and salinization of the Aral Sea

Aral Sea was once one of the largest inland sea. Main rivers that feed it have been deviated for cotton cultivation. Leading to a water volume lost of almost 60% and increasing salt concentration, killing commercial fishing trade and diffusing toxic wind storm affecting people health.

Similar work could be envisaged focusing on the Black Sea catchment for instance showing glacier retreat, detecting and analyzing the impact of major fire events (forest and grassland fires, potentially encroaching urban areas and settlements, inadequate agricultural practices, peatland fires, etc.), detecting and highlighting floods, taking place within Black Sea Catchment (emphasis on eastern parts of the BS Catchment) and also highlighting the management of national parks, forest, coastal zone and urbanization.

Moreover each site could be enriched by ground truth photography and local actor interview. A possible collaboration with a professional photograph reporter could be established.

6.5 Videos

Another very pedagogical way to illustrate changes across time is to create animated images using consecutive satellite images. Very good examples could be seen on the well known video sharing website "*Youtube*":

- Mesopotamians marshes (http://www.youtube.com/watch?v=MS1ynBO-ELQ)
- Dubai urbanisation (http://www.youtube.com/watch?v=rDcQtg6Bgvo)
- Deforestation (http://www.youtube.com/watch?v=G0uR-dKsFyU&feature=fvst)
- Lake Powell Drying (http://www.youtube.com/watch?v=yzBt5CsiUEM)

6.6 Cartography

The implementation of a long-time observation system of a remarkable region (for example ecosystem, National Park) by classifying satellite imagery on a continuous basis (monthly, seasonally, annually) constitute a good way to enrich the database of a region and share this information widely throughout web services. Satellite-based surveillance provides an excellent tool to monitor the changes of a region with a repeatable and systematic method. Similar work done for the Mesopotamian marshlands could also be implemented around the Black Sea.

7 Work implementation

7.1 Partners organisation

Technically remote sensing task will be spread across three institutions (ITU, GeoGraphic, UNIGE) who share a great experience and knowledge in remote sensing applied in environmental science.

According to common experiences a wide range of themes could be approached, we propose to focuses on landcover/landuse changes, and ecosystem monitoring at local scale within the already defined case studies Igneada, West Stara Planina, and Rioni river basin. Other specific themes like glacier retreat, floods, fire, and deforestation could be illustrated in the digital atlas.

We will supply general support for the EG community specially providing WP with global data useful for the hydrological modeling and assistance to WP3 which works on scenarios of change.

Moreover possible synergy with other European and/or local projects for example FP7 Pegaso[6] project (Danube Delta, Sebastopol Bay) should be kept in mind.

Finally some RS scenarios like real-time products should be envisaged to be implemented in the GRID-SDI infrastructure to allow rapid response (alert monitoring) to unexpected events like floods, fire…

The use of common RS and GIS software will facilitate exchanges, below a list of software in use within each institution (Table 7).

Table 7 RS/GIS software in use within each institution

GeoGraphic	ITU	UNIGE
ERDAS Imagine 9.3**:** Professional, MosaicPro, AutoSync, VirtualGIS	Erdas Imagine 9.1	ERDAS Imagine 9.2
ArcGIS 9.3 (ArcInfo)	ArcGIS 9.2	ArcGis 9.3 (ArcInfo)
Leica Photogrammetry Suite): Core, Productivity Bundles, Stereo, Terrain Editor, ORIMA DP	Envi+ IDL 4.4 PCI Geomatica 9.0	Definiens Developer 7 (eCognition) Idrisi Andes

[6] **P**eople for **E**cosystem Based **G**overnance in **A**ssessing **S**ustainable Development of **O**cean and Coast

7.2 Metadata Formulary

Relevant remote sensing data and derivate products as well as their metadata will be included in the EnviroGRIDS Spatial Data Infrastructure (EG-SDI)

Metadata are essential as they describe the data, allowing a user to evaluate and discover the data before using them. They must fill-in a mandatory basis. The metadata shall include information on how to access the data or at least identify the person to be contacted to access the datasets.

The metadata stored in the EG-SDI will compile according to international and fed on a continuous basis by the partners tough a web interface. .

These standards will be implemented in EnviroGRIDS through the metadata guidelines production and integration, as well as through data geoservices and data geoprocessing services that will be designed around OGC specifications.

The ISO 19115 standard defines (with more than 400 metadata elements, 20 core mandatory elements) how to describe a georeferenced information and provide information about the content, the identification, the quality, the spatial and temporal extent, the access and rights and the spatial reference.

This standard is applicable to:

- the cataloguing of datasets, clearinghouse activities, and the full description of datasets,
- geographic datasets, dataset series, and individual geographic features and features properties.

The main applicability of ISO19115 is for digital data but its principles can be extended and applied to other forms of geospatial data such as maps, charts and textual documents as well as non-geographic data (ISO, 2003).

The ISO 19139 standard complements ISO19115 by defining an XML encoding schema implementation specifying the metadata record format and may be used to describe, validate, and exchange geospatial metadata prepared in XML.

8 Learning more about remote sensing

Different remote sensing tutorials and notes are available about variety of applications based on remote sensing technology. With the help of these tutorials and notes it is possible to learn about basic satellite technologies for different disciplines. Some of the links are listed below:

8.1 Remote Sensing Tutorials and Notes

In this section, information on useful tutorial and notes are given to allow readers to further learn about remote sensing.

Table 8 Remote Sensing Tutorial and Notes

Center & document names	Web link
NASA The Remote Sensing Tutorial (Dr. Nicholas Short)	http://rst.gsfc.nasa.gov/
Natural Resources Canada, Canada Centre for Remote Sensing	http://www.ccrs.nrcan.gc.ca/resource/tutor/fundam/index_e.php
ISPRS, International Society for Photogrammetry and Remote Sensing	http://www.isprs.org/education/tutorials.aspx
Centre for Remote Imaging, Sensing and Processing,National University of Singapore	http://www.crisp.nus.edu.sg/~research/tutorial/rsmain.htm
University of Arizona, Geospatial Tools for Natural Resource Management	http://rangeview.arizona.edu/Tutorials/
Science Centre Singapore, Ressources	http://www.science.edu.sg/
Columbia University, Center for International Earth Science Information Network	http://www.ciesin.org/TG/RS/RS-home.html

8.2 Remote Sensing Journals

Several journals include remote sensing technology and environmental applications based on remotely sensed data in their scope. A list of the most popular journals is given in the following table.

Table 9 Main Remote Sensing Journals

Journals	Publisher
Geophysical Research Letters	American Geophysical Union (AGU)
Global Biogeochemical Cycles	American Geophysical Union (AGU)
Agricultural and Forest Meteorology	Elsevier B.V.
Computers & Geosciences	Elsevier B.V.
Geocarto International	Geocarto International Centre, Hong Kong
Canadian Journal of Forest Research	NRC Research Press
Canadian Journal of Remote Sensing	NRC Research Press
IEEE - Transactions on Geoscience and Remote Sensing	IEEE Geoscience and Remote Sensing Society
International Journal of Remote Sensing	Taylor and Francis
Remote Sensing Reviews	Taylor and Francis
Photogrammetric Engineering & Remote Sensing (PE&RS)	ASPRS, American Society for Photogrammetry Remote Sensing
Remote Sensing of Environment	Elsevier Inc.

9 Conclusions and recommendations

Conclusions

This guideline was written in order to serve as source of references for enviroGRIDS partners and other end users that would like to better understand the potential of remote sensing in Earth Observation.

It first introduces basic concepts of satellite and airborne remote sensing. It covers also the basic steps from image pre-processing, index calculations, through to different classification methods. It presents also many examples of possible applications in environmental sciences.

The contribution of remote sensing to bring data for hydrological modeling such as SWAT is visited.

Other very useful information on remote sensing sensors and data are presented in this deliverable, as well as examples of applications, tutorials and useful journals references.

This guideline presents also a good overview of what can be achieved according to the shared experience of the three institutions in charge of this task (ITU, GeoGraphic, UNIGE). The potential of remote sensing products will be demonstrated from local to the full Black Sea catchment scale:

- By answering specific EnviroGRIDS user needs in terms of RS analyses.
- For SWAT modeling, remote sensing could provide supplementary support on NDVI time series analysis while soil moisture products could be interesting for calibrating the models.
- Remote sensing meteorological data could also be provided as SWAT input.
- Trough case studies on biodiversity, ecosystem protection, coastal erosion, land cover change, floods, fires, development pressures, and climate change impacts by the implementation of observation system.
- With a digital atlas of environmental changes inspired by “One Planet Many People” published by the United Nations Environment Programme (UNEP, 2005).

Recommendations

Based on this short review of remote sensing related technologies and given the human resources available in the EnviroGRIDS project, we first strongly recommend to query the wide range of experience found within project partners to set the priorities for the remote sensing data and analyses. This should be achieved by a new survey on partners needs.

Other general recommendations are:

- to use medium to high resolution images, freely available or at low cost, on the internet or through specific agreements.
- to develop synergies with other local and/or European projects such as FP7 PEGASO to built up spatially explicit sustainability indicators and derive harmonized indicator subsets visualizing vulnerabilities across the river basins and the coastal zones of the Southern European and the Black Sea countries
- to strengthen the collaboration with GENESI-DR to improve data access to the EnviroGRIDS community. In this context we can offer our expertise in image analyses to contribute to develop of new products including web processing for simple image classification, NDVI and change detection analysis.
- to guarantee that all remote sensing products of the project are interoperable according to European INSPIRE standards and are made available to GEOSS trough the EnviroGRIDS platform.

These combined actions aim at increasing environmental awareness in the Black Sea region at all levels (governmental agencies, non-governmental organizations, general public and education) by building the capacity of enviroGRIDS partners and beyond to use modern Earth Observations Systems that are partially based on remote sensing.

Abbreviations and Acronyms

AATSR	Advanced Along Track Scanning Radiometers
AIRS	Atmospheric Infrared Sounder
AISA	Airborne Imaging Spectrometer for Applications
ALI	Advanced Land Imager
ALOS	Advanced Land Observing Satellite
AMI	Active Microwave Instrumentation
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AMSU	Advanced Microwave Sounding Unit
ASAR	Advanced Synthetic Aperture Radar
ASAS	Advanced Solid State Array Spectroradiometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible Infrared Spectrometer
AVNIR	Advanced Visible and Near Infrared Radiometer
BSC	Black Sea Catchment
CASI	Compact Airborne Spectrographic Imager
CERES	Clouds and Earth's Radiant Energy System
DAIS	Digital Airborne Imaging Spectrometer
DEM	Digital Elevation Model
DOS	Dark Object Substraction
DoW	Document of Work
EG	EnviroGRIDS
EM	Electro Magnetic
EVI	Enhanced Vegetation Index
EOS	Earth Observing System
EPS	Environmental Probe System
ERS	European Remote Sensing Satellite
ERSDAC	Earth Remote Sensing Data Analysis Center
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
FNEA	Fractal Net Evolution Approach
GCP	Ground Control points

GDEM	Global Digital Elevation Model
GENESI-DR	Ground European Network for Earth Science Interoperations - Digital Repositories
GeoGraphic	GIS&RS Consulting Center in Georgia
GEOSS	The Global Earth Observation System of Systems
GIS	Geographic Information System
GOME	Global Ozone Monitoring Experiment
GRID-Europe	Global Resource Information Database-Europe
G-SDI	Grid-enabled Spatial Data Infrastructure
HRV-IR	High Resolution Visible, Infrared
HSB	Humidity Sounder for Brazil
HYDICE	Hyperspectral Digital Imagery Collection Experiment
IBAs	Important Birds Areas
ICPDR	International Commission for the Protection of the Danube River
ICZM	Integrated Coastal Zone Management
IFOV	Instantaneous Field of View
IGBP	International Geosphere Biosphere Programme
IMOS	Iraqi Marshlands Observation System
IPAR	Intercepted photosynthetically active radiation
ISODATA	Iterative Self- Organizing Data Analysis
ITU	Istanbul Technical University
LAI	Leaf Area Index
LP DAAC	Land Processes Distributed Archive Center
MERIS	Medium Resolution Imaging Spectrometer
METI	Ministry of Economy, Trade and Industry
MISR	Multi-angle Imaging Spectro-Radiometer
MIVIS	Multispectral Infrared and Visible Imaging Spectrometer
MMS	Multispectral Scanner System
MODIS	Moderate Resolution Imaging Spectroradiometer
MODTRAN	MODerate spectral resolution atmospheric TRANSsmittance
MOPITT	Measurement of Pollution in the Troposphere
MoU	Memorandum of Understanding
MSAVI	Modified Soil Adjusted Index
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NDVI	Normalized Vegetation Index
NGA	National Geospatial-Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration

OBIA	Object-Based Image Analysis
OMI	Ozone Monitoring Instrument
PEGASO	People for Ecosystem Based Governance in Assessing Sustainable Development of Ocean and Coast
PRISM	Panchromatic Remote Sensing Instrument for Stereo Mapping
PVI	Perpendicular Vegetation Index
Radar	RAdio Detection And Ranging
REP	Red Edge Position
RMSE	Root Mean Square Error
ROSIS	Reflective Optics System Imaging Spectrometer
RS	Remote Sensing
RVI	Ratio Vegetation Index
SAM	Spectral Angle Mapper
SAR	Synthetic Aperture Radar
SAVI	Soil Adjusted Vegetation Index
SeaWiFS	Sea-viewing Wide Field Sensor
SMAC	Simplified Method for the atmospheric correction
SMIFTS	Spatially Modulated Imaging Fourier Transform Spectrometer
SoE	State of the Environment
SPOT	Système Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SSM	Surface Soil Moisture
SST	Sea Surface Temperature
SWACI	Space Weather Application Center Ionosphere
SWAT	Soil Water Assessment Tool
SWI	Soil Water Index
SwissED	Swiss Environmental Domain
TM	Thematic Mapper
TSAVI	Transformed Soil Adjusted Vegetation Index
UNEP	United Nations Environment Programme
UNIGE	Geneva University
VI	Vegetation Indices
WP	Work Package

Annexes

A. Satellite and Sensor Specification

Satellite	Sensor	Spectral Resolution (µm)	Spatial Resolution	Temporal Resolution	What Can Be Detected	
					Spatial	Temporal
LANDSAT 4,5	**MMS** (Multispectral scanner system)	1: 0.5-0.6 (G) 2: 0.6-0.7 (R) 3: 0.7-0.8 (VNIR) 4: 0.8-1.1 (NIR)	80 m; 185 Km swath width	16 days	Mapping coastal features Roads and urban mapping Vegetation studies and mapping land/water boundaries	Deforestation Urban and suburban development
	TM Thematic Mapper	1: 0.45-0.515 (B) 2: 0.52-0.60 (G) 3: 0.63-0.69 (R) 4: 0.75-0.90 (NIR) 5: 1.55-1.75 (Mid-IR) 6 (thermal): 10.40-12.5 7: 2.09-2.35 (Mid-IR)	30 m (visible, near and mid-IR); 120 m (thermal IR); 185 Km swath width	16 days	Soil/vegetation differentiation & coastal water mapping Vegetation mapping Plant species differentiation Biomass survey Snow/cloud differentiation Thermal mapping Geological mapping	Changes in heat islands Changes in vegetation and land use patterns
LANDSAT 7 (1, 2, 3, 6 are inactive)	**ETM +** (Enhanced Thematic Mapper)	1: 0.45-0.515 (B) 2: 0.52-0.60 (G) 3: 0.63-0.69 (R) 4: 0.75-0.90 (NIR) 5: 1.55-1.75 (Mid-IR) 6 (thermal): 10.40-12.5 7: 2.09-2.35 (Mid-IR) 8 (pan): 0.52-0.90	30 m (visible, near and mid-IR), 15 m (panchromatic), 60 m (Thermal Infrared); 185 Km swath width	16 days	Urbanization Forest Stands Agricultural Plots Coastline Advance/Retreat Sea Ice Coverage	Changes in land use/ land cover Development patterns Migration patterns Agricultural variations Urban/Rural interchange

SPOT 1, 2, 4 and 5 **(3 is inactive) Launched by France from 1986-1998.** **SPOT 5 was launched in May 2002.** **SPOT VEGETATION**	**Two HRV-IR** (High Resolution Visible, Infrared) push-broom sensors. VGT-P products (physical values) VGT-S1 products) VGT-S10 products VGT D10 products	1: 0.50-0.59 (G) 2: 0.61-0.68 (R) 3: 0.79-0.89 (NIR) 4: 1.58-1.73 (SWIR) added on SPOT 4 Pan: 0.51-0.73	20 m (Visible, Near Infrared), 10 m (panchromatic); 60 Km swath width 10m ((Visible, Near Infrared), 2.5 m (panchromatic); 60 Km swath width 1 km	26 days 26 days Daily, Daily MVC (Maximum Value Composite) Syntheses Ten-day MVC synthesis, also in degraded resolution Ten day BDC (BiDirectional Composite) synthesis, also in degraded resolution)	Agricultural (Resource mapping, production management, crop classification) Land Use (Urban and suburban land use, land mapping, energy, human infrastructure) Oceanography (water quality management) Water resources (Surface water, soil moisture and evapotranspiration, lakes and rivers studies, wetlands and habitat mapping, resource assessment) Geological applications (mapping, economic geology, engineering geology, hazards and land morphology, oil and gas exploration) Engineering applications (terrain analysis, site investigation, water resources engineering, transport studies. Forest monitoring (inventory, forest management) and vegetation cover study	Deforestation Suburban/Urban land use changes Residential Development Coastal Pollution Water resource pollution monitoring Snow and Ice mapping Harvest forecasting Conservation monitoring Hazard prediction Landslide hazards Forest damage assessment

EO-1 (Earth Observation)	Hyperion (Spaceborn Hyperspectral)	0.4 to 2.5 µm in 220 bands	30 m 7.7*42 or 108 km	16 day	Geological Survey Mineral Mapping Vegetation Mapping Invasive vegetation Mapping Forest Mapping	Mineral Mapping Vegetation Mapping Forest Mapping
	ALI Advanced Land Imager	0.4 to 2.5 µm in 10 bands	30 m 37*42 or 108 km	16 day	Vegetation Mapping Forest Mapping Land Cover/Use	Vegetation Mapping Forest Mapping Land Cover/Use
IKONOS 1, 2 **Launched in 1999 (IKONOS 2 failed)**	**MMS** (Multispectral) and PAN (Panchromatic)	1: 0.45-0.53 (B) 2: 0.52-0.61 (G) 3: 0.64-0.72 (R) 4: 0.76-0.88 (VNIR) Pan: 0.45 -0.90	4 m (visible), 1 m (panchromatic); 11 Km swath width	26 days (680 km sun-synchronous orbit)	Roads, vehicles, buildings, infrastructure (panchromatic) Land use, agricultural uses, vegetation (color imager)	Changes in human infrastructure Development patterns Migration patterns Agricultural variations Urban/Rural interchange
Quickbird **Launched in 2001**	**MS** (Multispectral) and PAN (Panchromatic)	1: 0.45-0.52 (B) 2: 0.52-0.60 (G) 3: 0.63-0.69 (R) 4: 0.76-0.99 (NIR) Pan: 0.45-0.90	2.44 m (Multispectral); 61 cm (panchromatic); 16.5 Km swath width	1 to 3.5 days depending on latitude at 70-centimeter resolution	Roads, vehicles, buildings, infrastructure (panchromatic) Land use, agricultural uses, vegetation (color imager)	Changes in human infrastructure Development patterns Migration patterns Agricultural variations Urban/Rural interchange
The Advanced Land Observing Satellite (ALOS)	**PRISM:** Panchromatic Remote-sensing Instrument for Stereo Mapping	0.52 - 0.77 µm (G)	2.5 m 70 m Swath width	46 days	Mapping DEM generation	

Launched in 2006	**AVNIR-2:** Advanced Visible and Near Infrared Radiometer type 2	1: 0.42 - 0.50 (B) 2: 0.52 - 0.60 (G) 3: 0.61 - 0.69 (R) 4: 0.76 - 0.89 (NIR)	10 m 70 m Swath width	46 days	Mapping DEM generation	
NOAA - 7 **Launched in 1981 and deactivated 1986 due to an power failure**	**AVHRR** (Advanced Very High Resolution Radiometer)	1: 0.58-0.68 (G and R) 2: 0.72-1.10 (NIR) 3: 3.53-3.93 (Mid-IR) 4: 10.3-11.3 (Thermal IR) 5: 11.5-12.5 (Thermal IR)	4.4 Km (Global Area Coverage), 1.1 Km (Local Area Coverage); 2800 Km swath width	2 times per day; 8-day and monthly averaged data available	Day and night cloud top and sea surface temperatures Ice and snow conditions	Changes in climate and global land and sea temperatures Changes in snow and ice coverages
AVIRIS **Airborne Visible Infrared Spectrometer (instrument on board of planes)**	**Hyperspectral airborne sensor** Uses a scanning mirror in a wisk brom manner	Contains 224 different detectors each with a wavelength sensitive range of 10 nm, allowing it to cover the entire range between 0,4 and 2,5 µm.	20 m (high altitude), 4 m (low altitude); 11 Km swath width	Only scheduled flights	Ecology (chlorophyll, leaf water, lignin, cellulose, pigments, structure, non-photosynthetic constituents) Geology (mineralogy, soil type) Cloud and Atmospheric studies (water vapor, clouds properties, aerosols, absorbing gases) Oceanography/Coastal and Inland Waters (chlorophyll, dissolved organics, sediments, bottom composition, bathymetry) Snow and Ice Hydrology (grainsize, impurities) Biomass burning (smoke, combustion products)	Snow and Ice Hydrology (melting, snow cover fraction) Commercial (agricultural correction) Ecology (changes in vegetation and community maps) Oceanography (changes in plankton coverage and chlorophyll) Forest Fires

					Environmental Hazards Commercial	
ERS2 (Active)	**AMI** (Active Microwave Instrumentation) with SAR-Image Mode, SAR-Wave Mode, Scatter-ometer Mode and Radar Altimeter	5.3 GHz (C-Band) 13.5 GHz for the Radar Altimeter	30 m (SAR) 50 Km (Scatter-ometer); 80-100 Km swath width (SAR-Image mode); 5 Km swath width (SAR-Wave mode), 500 Km swath width (Scatterometer mode)	3 day, 35 day or 168 day cycles	All-weather instrument Ocean wave height/lengths, wind speed/direction, ice parameters, sea surface & cloud top temperatures, cloud cover and atmospheric water vapor.	Alterations and observations in ocean, land, ice, atmosphere, and climate Flood activity Changes in ocean activity, coastal regions and ice caps
	ATSR-M (Along Track Scanning Radiometer with Microwave Sounder)	1.6, 3.7, 11, 12 (IR), 23.5 and 36.5 GHZ (Microwave)	1 Km (IR), 22 Km (Microwave); 500 Km swath width	3 day, 35 day or 168 day cycles	All-weather instrument Ocean wave height/lengths, wind speed/direction, ice parameters, sea surface & cloud top temperatures, cloud cover and atmospheric water vapor.	Alterations and observations in ocean, land, ice, atmosphere, and climate Flood activity Changes in ocean activity, coastal regions and ice caps
	GOME (Global Ozone Monitoring Experiment). Sensor is a double spectrometer	1: 0.24-0.295 2: 0.29-0.405 3: 0.40-0.605 4: 0.59-0.79	40 x 2Km 40 x 320 Km; 960 Km swath width			

	AATSR (Advanced Along Track Scanning Radiometer)	0.65, 0.85, 1.27, 1.6	0.5 Km; 500 KM swath width			
SEASTAR	**SeaWiFS** (Sea-viewing Wide Field Sensor)	1: 0.402-0.422 2: 0.433-0.453 3: 0.480-0.5 4: 0.5-0.520 5: 0.545-0.565 6: 0.66-0.68 7: 0.745-0.785 8: 0.845-0.885	1.1 Km (local area coverage) 4.5 Km (global area coverage); 285 Km swath width	1 day	Ocean color and chlorophyll Subsurface scattering Atmospheric correction Atmospheric correction Sea-surface temperature	Changes in phytoplankton Designed to provide global coverage of the oceans on a regular basis
TERRA **Launched December 1999**	**ASTER** (Advanced Spaceborne Thermal Emission and Reflection Radiometer)	14 bands, with wavelengths ranging from 0.52 to 11.65	15 m (VNIR), 30 m (SWIR), 90 m (TIR); 60 Km swath width	4-16 days By request	Urbanization Forest Stands Agricultural Plots Coastline Advance/Retreat Rugged Topography Sea Ice Coverage DEM generation	Infrastructure Changes Residential Developments Deforestation/Reforestation Harvest Flood Area Landslides & Mass Movements

	MODIS (Moderate Resolution Imaging Spectro-Radiometer)	36 bands, with wavelengths ranging from 0.405 to 14.38	250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36); 2330 x 10 Km swath width	1 to 2 days	Ideal for large scale changes in the biosphere, measures photosynthetic activity of land and marine plants Surface temperature measurements, Deforestation Forests, Open Canopy Vegetation, Large Scale Agriculture Water Clarity, Atmospheric Aerosols, Smoke Plumes, Snow Cover, Ocean Temperature	Forest Fires Regional Harvest/ Cycles Plankton Blooms Sediment Plumes Maps extent of snow and ice brought by winter storms and frigid conditions
	MISR (Multi-angle Imaging Spectro-Radiometer)	4 bands, with wavelengths ranging from 0.44 to 0.86	275 m; 360 Km swath width	9 days	The amount of sunlight scattered in the atmosphere under natural conditions, Atmospheric aerosol particles (formed by both natural and human activities) Cloud Cover/Type, Vegetation Type	Smoke Plumes Regional Air Quality Climate Regional Forest Canopy Structure
	CERES (Clouds and Earth's Radiant Energy System)	Shortwave: 0.3-5 Longwave: 8-12 Total: 0.3->200	20 km	Daily	Cloud/radiation flux measurements for models of oceanic and atmospheric energetics The cross track mode continues measurements of Earth Radiation Budget Experiment and Tropical Rainfall Measuring Mission	Contributes to wider range weather forecasting
	MOPITT (Measure-ment of Pollution in the Tropo-sphere)	2.3 (CH_4) 2.4 and 4.7 (CO)	22 Km horizontally and 3 Km vertically; 640 Km swath width	3 -4 days	Measurements of pollution in the troposphere Used to determine the amount of Carbon dioxide and methane in the atmosphere	

AQUA **Launched May 2002**	**MODIS** (Moderate Resolution Imaging Spectro-Radiometer)	36 bands, with wavelengths ranging from 0.405 to 14.38	250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36); 2330 x 10 Km swath width	1 to 2 days	Ideal for large scale changes in the biosphere, measures photosynthetic activity of land and marine plants Surface temperature measurements, Deforestation Forests, Open Canopy Vegetation, Large Scale Agriculture Water Clarity, Atmospheric Aerosols, Smoke Plumes, Snow Cover, Ocean Temperature	Forest Fires Regional Harvest/ Cycles Plankton Blooms Sediment Plumes Maps extent of snow and ice brought by winter storms and frigid conditions
	CERES (Clouds and Earth's Radiant Energy System)	Shortwave: 0.3-5 Longwave: 8-12 Total: 0.3->200	20 km	Daily	Cloud/radiation flux measurements for models of oceanic and atmospheric energetics The cross track mode continues measurements of Earth Radiation Budget Experiment and Tropical Rainfall Measuring Mission	Contributes to wider range weather forecasting
	AMSR/E (Advanced Microwave Scanning Radiometer)	12 channels and 6 frequencies ranging from 6.9 to 89.0 GHz (center frequency at 6.925, 10.65, 18.7, 23.8, 36.5 and 89.0 GHz)	Ranging from 56 km (at 6.925 GHz) to 5.4 km (at 89.0 GHz); 1445 km swath width	Daily	Cloud properties; radiative energy flux; precipitation; land surface wetness; sea ice; snow cover; sea surface temperature; sea surface wind fields	Contributes to weather forecasting and Climate Models
	AIRS (Atmospheric Infrared Sounder)	2,300 spectral channels in the range of 0.4 to 1.0 and 3.4 to 15.4	13.5 km (IR) and 2.3 km (VIS/NIR); 1650 km swath width	Daily	Measures atmospheric temperature and humidity; land and sea surface temperatures; cloud properties; radiative energy flux	

	AMSU (Advanced Microwave Sounding Unit) Consists of two sensors: AMSU-A1 ans AMSU-A2	15 discrete channels in the range of 50 to 89 GHz	40 km; 1650 km swath width	Daily	Measures atmospheric temperature and humidity	
	HSB (Humidity Sounder for Brazil)	4 channels: 1 at 150 GHz, 3 at 183 GHz	13.5 km; 1650 km swath width	Daily	Aimed at obtaining humidity profiles throughout the atmosphere	
Cartosat-1 **Launched in 2005**		Two panchromatic cameras that take black-and-white stereoscopic pictures in the visible region.	2,5 m 30 km swath width	116 days	Urban and Rural area mapping Land and water resource management Disaster assessment Environmental Impact Assessment	Land cover change detection
Geoeye-1 **Launched in 2008**		450-520 nm (blue) 520-600 nm (green) 625-695 nm (red) 760-900 nm (near IR) 450-900 nm (Pan)	1.65 m 0.41 m 15.2 km swath width	Less than 3 days	Roads, buildings, infrastructure (panchromatic) Land use (color imager)	Changes in human infrastructure Development patterns Migration patterns Urban/Rural interchange

B. Satellites and sensors, with links to appropriate websites

SATELLITES & SENSORS	WEBSITES
AIRS (Atmospheric Infrared Sounder)	http://airs.jpl.nasa.gov/ http://www-airs.jpl.nasa.gov/
ALI (Advanced Land Imager)	http://eo1.gsfc.nasa.gov/Technology/ALIhome1.htm
ALOS (Advanced Land Observation Satellite)	http://www.tec.army.mil/tio/ALOS.htm
AMSU (Advanced Microwave Sounding Unit)	http://amsu.ssec.wisc.edu/
AMSR-E (Advanced Microwave Scanning Radiometer for EOS)	http://wwwghcc.msfc.nasa.gov/AMSR/ http://nsidc.org/daac/amsre/
AQUA	http://asd-www.larc.nasa.gov/ceres/aqua/
ASTER (Advanced Spaceborne Thermal Emission and Reflection Radio	http://asterweb.jpl.nasa.gov/ http://edc.usgs.gov/products/satellite/aster.html http://visibleEarth.nasa.gov/view_set.php?sensorName=ASTER
ATSR (Along Track Scanning Radiometer)	http://www.atsr.rl.ac.uk/
CERES (Clouds and Earth's Radiant Energy System)	http://asd-www.larc.nasa.gov/ceres/ASDceres.html http://eosweb.larc.nasa.gov/PRODOCS/ceres/table_ceres.html http://Earthobservatory.nasa.gov/Observatory/Datasets/netflux.erbe.html http://Earthobservatory.nasa.gov/Observatory/Datasets/swflux.erbe.html
EOS (Earth Observing System)	http://eospso.gsfc.nasa.gov/
EO-1 (Earth Observing-1)	http://eo1.gsfc.nasa.gov/ http://eo1.gsfc.nasa.gov/miscPages/home.html http://www.tec.army.mil/tio/EO-1newtables.htm http://edc.usgs.gov/products/satellite/eo1.html http://eo1.usgs.gov/ http://www.crisp.nus.edu.sg/~research/tutorial/eo1.htm
ERS (European Remote Sensing Satellite)	http://Earth.esa.int/ers/ http://www.rsi.ca/products/sensor/ers/ers_price.asp http://www.tec.army.mil/tio/ERS.htm http://www.crisp.nus.edu.sg/~research/tutorial/ers.htm
ETM+ (Enhanced Thematic Mapper Plus)	http://visibleEarth.nasa.gov/view_set.php?sensorID=11
MERIS (Medium Resolution Imaging Spectrometer)	http://envisat.esa.int/instruments/meris/index.html
MISR (Multi-angle Imaging SpectroRadiometer)	http://www-misr.jpl.nasa.gov/ http://eosweb.larc.nasa.gov/PRODOCS/misr/table_misr.html http://visibleEarth.nasa.gov/view_set.php?sensorName=MISR
MOPITT (Measurements of Pollution in the Troposphere)	http://www.atmosp.physics.utoronto.ca/MOPITT/home.html http://visibleEarth.nasa.gov/view_set.php?sensorName=MOPITT
QUICKBIRD	http://www.rsi.ca/products/sensor/quickbird/qb_price.asp http://www.tec.army.mil/tio/QUICKBIRD.htm http://www.crisp.nus.edu.sg/~research/tutorial/quickbird.htm
TERRA	http://terra.nasa.gov/ http://asd-www.larc.nasa.gov/ceres/terra/ http://visibleEarth.nasa.gov/view_set.php?sensorName=Terra
IKONOS	http://www.geoeye.com/CorpSite/products/imagery-sources/Default.aspx#ikonos
SPOT IMAGE	http://www.spotimage.com/
HYPERION-EO1	http://eo1.usgs.gov/hyperion.php
SPOT VEGETATION	http://www.spot-vegetation.com/
NOAA-7	http://www2.ncdc.noaa.gov/docs/podug/html/c1/sec1-43.htm http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
Seastar/ SeaWİFS	http://oceancolor.gsfc.nasa.gov/SeaWiFS/

C. MODIS Products

SHORTNAME	PLATFORM	MODIS Product	RASTER TYPE	RES (m)	TEMPORAL GRANULARITY
MCD12Q1	Combined	Land Cover Type	Tile	500m	Yearly
MCD15A2	Combined	MODIS/Terra+Aqua Leaf Area Index/FPAR 8-Day L3 Global 1km SIN Grid V005	Tile	1000m	8 Day
MCD43A1	Combined	BRDF-Albedo Model Parameters	Tile	500m	16 Day
MCD43A2	Combined	BRDF-Albedo Quality	Tile	500m	16 Day
MCD43A3	Combined	Albedo	Tile	500m	16 Day
MCD43A4	Combined	Nadir BRDF-Adjusted Reflectance	Tile	500m	16 Day
MCD43B1	Combined	BRDF-Albedo Model Parameters	Tile	1000m	16 Day
MCD43B2	Combined	BRDF-Albedo Quality	Tile	1000m	16 Day
MCD43B3	Combined	Albedo	Tile	1000m	16 Day
MCD43B4	Combined	Nadir BRDF-Adjusted Reflectance	Tile	1000m	16 Day
MCD43C1	Combined	BRDF-Albedo Model Parameters	CMG	5600m	16 Day
MCD43C2	Combined	BRDF-Albedo Snow-free Quality	CMG	5600m	16 Day
MCD43C3	Combined	Albedo	CMG	5600m	16 Day
MCD43C4	Combined	Nadir BRDF-Adjusted Reflectance	CMG	5600m	16 Day
MCD45A1	Combined	Burned Area	Tile	500m	Monthly
MOD09A1	Terra	Surface Reflectance Bands 1–7	Tile	500m	8 Day
MOD09CMG	Terra	Surface Reflectance Bands 1–7	CMG	5600m	Daily
MOD09GA	Terra	Surface Reflectance Bands 1–7	Tile	500/1000m	Daily
MOD09GQ	Terra	Surface Reflectance Bands 1–2	Tile	250m	Daily
MOD09Q1	Terra	Surface Reflectance Bands 1–2	Tile	250m	8 Day
MOD11_L2	Terra	Land Surface Temperature & Emissivity	Swath	1000m	5 Min
MOD11A1	Terra	Land Surface Temperature & Emissivity	Tile	1000m	Daily
MOD11A2	Terra	Land Surface Temperature & Emissivity	Tile	1000m	8 Day

MOD11B1	Terra	Land Surface Temperature & Emissivity	Tile	6000m	Daily
MOD11C1	Terra	Land Surface Temperature & Emissivity	CMG	5600m	Daily
MOD11C2	Terra	Land Surface Temperature & Emissivity	CMG	5600m	8 Day
MOD11C3	Terra	Land Surface Temperature & Emissivity	CMG	5600m	Monthly
MOD13A1	Terra	Vegetation Indices	Tile	500m	16 Day
MOD13A2	Terra	Vegetation Indices	Tile	1000m	16 Day
MOD13A3	Terra	Vegetation Indices	Tile	1000m	Monthly
MOD13C1	Terra	Vegetation Indices	CMG	5600m	16 Day
MOD13C2	Terra	Vegetation Indices	CMG	5600m	Monthly
MOD13Q1	Terra	Vegetation Indices	Tile	250m	16 Day
MOD14	Terra	Thermal Anomalies & Fire	Swath	1000m	5 Min
MOD14A1	Terra	Thermal Anomalies & Fire	Tile	1000m	Daily
MOD14A2	Terra	Thermal Anomalies & Fire	Tile	1000m	8 Day
MOD15A2	Terra	Leaf Area Index - FPAR	Tile	1000m	8 Day
MOD17A2	Terra	Gross Primary Productivity	Tile	1000m	8 Day
MOD44B	Terra	Vegetation Continuous Fields	Tile	500m	Yearly
MYD09A1	Aqua	Surface Reflectance Bands 1–7	Tile	500m	8 Day
MYD09CMG	Aqua	Surface Reflectance Bands 1–7	CMG	5600m	Daily
MYD09GA	Aqua	Surface Reflectance Bands 1–7	Tile	500/1000m	Daily
MYD09GQ	Aqua	Surface Reflectance Bands 1–2	Tile	250m	Daily
MYD09Q1	Aqua	Surface Reflectance Bands 1–2	Tile	250m	8 Day
MYD11_L2	Aqua	Land Surface Temperature & Emissivity	Swath	1000m	5 Min
MYD11A1	Aqua	Land Surface Temperature & Emissivity	Tile	1000m	Daily
MYD11A2	Aqua	Land Surface Temperature & Emissivity	Tile	1000m	8 Day
MYD11B1	Aqua	Land Surface Temperature & Emissivity	Tile	6000m	Daily
MYD11C1	Aqua	Land Surface	CMG	5600m	Daily

		Temperature & Emissivity			
MYD11C2	Aqua	Land Surface Temperature & Emissivity	CMG	5600m	8 Day
MYD11C3	Aqua	Land Surface Temperature & Emissivity	CMG	5600m	Monthly
MYD13A1	Aqua	Vegetation Indices	Tile	500m	16 Day
MYD13A2	Aqua	Vegetation Indices	Tile	1000m	16 Day
MYD13A3	Aqua	Vegetation Indices	Tile	1000m	Monthly
MYD13C1	Aqua	Vegetation Indices	CMG	5600m	16 Day
MYD13C2	Aqua	Vegetation Indices	CMG	5600m	Monthly
MYD13Q1	Aqua	Vegetation Indices	Tile	250m	16 Day
MYD14	Aqua	Thermal Anomalies & Fire	Swath	1000m	5 Min
MYD14A1	Aqua	Thermal Anomalies & Fire	Tile	1000m	Daily
MYD14A2	Aqua	Thermal Anomalies & Fire	Tile	1000m	8 Day
MYD15A2	Aqua	Leaf Area Index - FPAR	Tile	1000m	8 Day
MYD17A2	Aqua	Gross Primary Productivity	Tile	1000m	11 Day

D. MODIS Standard Products

Geophysical Parameter Name	**Description**	**Units**
nLw_412	Normalized water-leaving radiance at 412 nm	mW·cm-2·µm-1·sr-1
nLw 443	Normalized water-leaving radiance at 443 nm	mW·cm-2·µm-1·sr-1
nLw_488	Normalized water-leaving radiance at 488 nm	mW·cm-2·µm-1·sr-1
nLw_531	Normalized water-leaving radiance at 531 nm	mW·cm-2·µm-1·sr-1
nLw_551	Normalized water-leaving radiance at 551 nm	mW·cm-2·µm-1·sr-1
nLw_667	Normalized water-leaving radiance at 667 nm	mW·cm-2·µm-1·sr-1
Tau_869	Aerosol optical thickness at 869 nm	dimensionless
Eps_78	Epsilon of aerosol correction at 748 and 869 nm	dimensionless
Chlor_a	OC3 Chlorophyll a concentration	mg·m-3
K490	Diffuse attenuation coefficient at 490nm	m-1
Angstrom_531	Angstrom coefficient, 531-869 nm	dimensionless
SST	Sea Surface Temperature - 11micron	degrees Celsius
SST4	Sea Surface Temperature - 4micron (nighttime only)	degrees Celsius

E. SeaWiFS Products

Geophysical Parameter Name	Description	Units
nLw_412	Normalized water-leaving radiance at 412 nm	mW·cm-2·µm-1·sr-1
nLw 443	Normalized water-leaving radiance at 443 nm	mW·cm-2·µm-1·sr-1
nLw_490	Normalized water-leaving radiance at 490 nm	mW·cm-2·µm-1·sr-1
nLw_510	Normalized water-leaving radiance at 510 nm	mW·cm-2·µm-1·sr-1
nLw_555	Normalized water-leaving radiance at 555 nm	mW·cm-2·µm-1·sr-1
nLw_670	Normalized water-leaving radiance at 670 nm	mW·cm-2·µm-1·sr-1
Tau_865	Aerosol optical thickness at 865 nm	dimensionless
Eps_78	Epsilon of aerosol correction at 765 and 865 nm	dimensionless
Chlor_a	OC4 Chlorophyll a concentration	mg·m-3
K490	Diffuse attenuation coefficient at 490nm	m-1
Angstrom_510	Angstrom coefficient, 510-865 nm	dimensionless

F. Other SeaWiFS Products

Geophysical Parameter Name	Description	Units
SeaWiFS Level 3 PAR	Photosynthetically Active Radiation from the sun 400-700 nm	Einstein/m2/day
SeaWiFS NDVI	Normalized Difference Vegetation Index	
SeaWiFS Land Reflectance	Land Reflectance	
SeaWiFS Biosphere	Biosphere product	

G. Accessing Land Cover Products @ BSC (MODIS & MERIS)

MODIS

MODIS combined Aqua and Terra land cover science product MCD12Q1 and its naming convention is explained on the example of Black Sea Catchment area. For example, the filename MCD12Q1.A2007001.h21v04.005.2009173182842.hdf indicates:

- MCD12Q1 - Product Short Name
- .A2007001 - Julian Date of Acquisition (A-YYYYDDD)
- .h21v04 - Tile Identifier (horizontalXXverticalYY)
- .005 - Collection Version
- .2009173182842 - Julian Date of Production (YYYYDDDHHMMSS)
- .hdf - Data Format (HDF-EOS)

Most standard MODIS Land products use Sinusoidal grid tiling system shown on the Figure 39 below. Tiles are 10 degrees by 10 degrees at the equator. The tile coordinate system starts at (0,0) (horizontal tile number, vertical tile number) in the upper left corner and proceeds right (horizontal) and downward (vertical). The tile in the bottom right corner is (35,17).

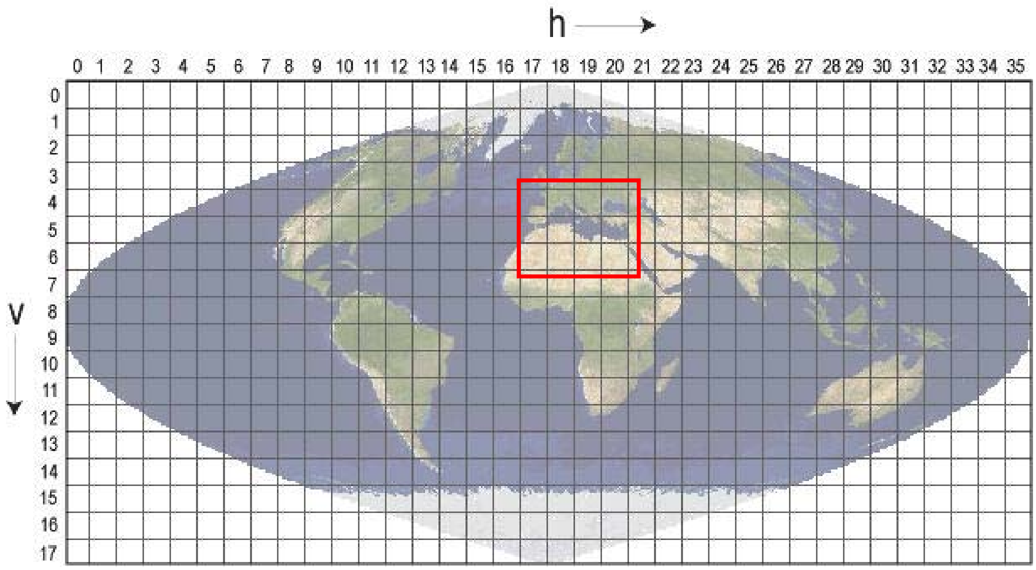

Figure 39 Data covering EnviroGRIDS@BSC belong to tiles h18v03 through h21v05 (highlighted)

Steps to access native MODIS combined land cover science data product MCD12Q1 are:

1. Surf to https://lpdaac.usgs.gov/lpdaac/get_data/data_pool webpage;
2. Click MODIS COMBINED under ACCESS THE DATA POOL (leads to ftp://e4ftl01u.ecs.nasa.gov/MOTA/);
3. Select MCD12Q1.005 to access via FTP land cover products for 2001-2007 (leads to ftp://e4ftl01u.ecs.nasa.gov/MOTA/MCD12Q1.005);
4. Select the year of interest 2001.01.01 through 2007.01.01;
5. Download HDF files of interest as well as respective metadata XML files. The Black Sea Catchment is covered by tiles h18-h21 through v03-v05 (see above Sinusoidal grid).

For convenience of project Partners and initial validation of standard MODIS land cover product usability for SWAT the HDF format files were downloaded from above source, processed into format, projection & extent required for ArcSWAT and result uploaded to EnviroGRIDS storage area at http://netstorage.unige.ch (Partner Username and Password is required to access target directory /NetStorage/DriveN@ENVIROGRIDS/GISDATA). Files are accompanied with respective symbology layer(s) and ArcMap document(s).

Following steps were involved in processing the native MODIS HDF land cover science product into the ArcSWAT for EnviroGRIDS compatible format:

ERDAS Imagine 9.3 and ArcGIS 9.3 proprietary software were used to:

1. Import all HDF format files into ArcSWAT compatible ESRI GRID format (using file conversion in ArcGIS environment);
2. Mosaicing yearly ESRI GRID files (MosaicPro tool of ERDAS);
3. Reproject mosaiced file from Sinusoidal projection (native to MODIS science product) into WGS84 Geographical Coordinate System (EnviroGRIDS official system);
4. Mosaic for each year cropped to EnviroGRIDS project extent (ERDAS);
5. Layer files and map document were created for convenience to display each data source (MODIS, MERIS) and each land cover classification scheme encoded in the datasets and presented on an yearly basis (in ArcGIS environment).

MERIS

MERIS Globcover products can be accessed in the following steps:

1. Surfing to webpage http://www.esa.int/due/ionia/globcover;
2. Open webpage at the link 'Global Land Cover Product' (link leads to ftp location ftp://uranus.esrin.esa.int/pub/globcover_v2/global) or 'Regional Land Cover Product' (leads to ftp://uranus.esrin.esa.int/pub/globcover_v2/regional);
3. Download zip file(s) which contain(s) a raster version of the Globcover global (or regional) land cover map(s) for the period from December 2004 to June 2006, in GEOTIFF format, where the ID values stand for the land cover classes values. Zip file(s) also contain(s), the Excel file with the legend of the global (and regional) land cover map, in which the ID values of the GEOTIFF raster are linked with the corresponding land cover labels and RGB codes. Colour map of the Globcover global (and regional) land cover in an ArcGIS symbology format (.lyr) file is contained as well.
4. File GLOBCOVER_Products_Description_Validation_Report_I2.1.pdf contains report with comprehensive explanation of the Globcover project and products (methods, legend and validation) (Bicheron P. et al., 2008).

Globcover product preview in native symbology and BSC extent is displayed below:

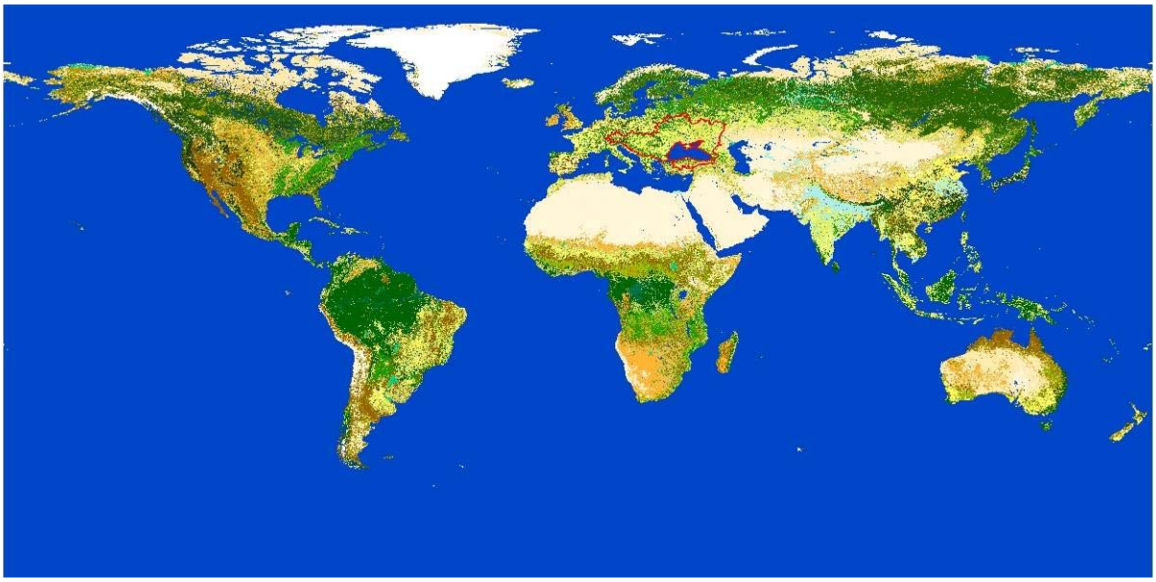

Figure 40 Illustration of Globcover product with BSC extent

For convenience of project Partners and initial validation of standard MERIS land cover product usability for SWAT the GEOTIFF format files were downloaded, processed into format, projection & extent required for ArcSWAT and result uploaded to EnviroGRIDS storage area at http://netstorage.unige.ch (Partner Username and Password is required to access target directory /NetStorage/DriveN@ENVIROGRIDS/GISDATA). Files are accompanied with respective symbology layer(s) and ArcMap document(s).

The native GEOTIFF files are in geographic coordinates (WGS84 ellipsoid).

ERDAS Imagine 9.3 and ArcGIS 9.3 proprietary software were used to:

1. Crop Globcover to EnviroGRIDS project extent;
2. Convert GEOTIFF files into the ArcSWAT compatible ESRI GRID format;
3. Layer files and map documents were created to display all data (MODIS, MERIS) and each land cover classification scheme encoded in the datasets and presented on a yearly basis.

H. Data Format Requirements for SWAT (Soil Water Assessment Tool)

Described below are the basic file format and compatibility requirements in order to create SWAT dataset using the ArcSWAT extension to ArcGIS. The ArcSWAT interface will need to access ArcGIS compatible raster (GRID file format) and vector datasets (shapefiles and feature classes) and database files which provide certain types of information about the watershed. The necessary spatial datasets and database files need to be prepared prior to running the interface, and respective requirements are concisely described below (Winchell et al., 2009).

Namely, the SWAT documentation defines requirements for land cover data as follows:

> The categories specified in the land cover/land use map will need to be reclassified into SWAT land cover/plant types. The user has three options for reclassifying the categories.
>
> The first option is to use a land cover/land use lookup table that is built into the ArcSWAT interface. The interface contains the USGS LULC and NLCD 1992 lookup tables in the SWAT2005.mdb database that identifies the different SWAT land cover/plant types used to model the various USGS LULC or NLCD 1992 land uses.
>
> The second option is to type in the 4-letter SWAT land cover/plant type code for each category when the land cover/land use map theme is loaded in the interface.
>
> The third option is to create a user look up table that identifies the 4-letter SWAT code for the different categories of land cover/land use on the map.

Land Cover/Land Use spatial dataset: ESRI GRID, Shapefile, or Feature Class Format

Defined Look Up Table (LUP) for the third option, built-in into SWAT structure is:

> The land use look up table is used to specify the SWAT land cover/plant code or SWAT urban land type code to be modeled for each category in the land use map grid.
>
> Because this information can be entered manually, this table is not required to run the interface.
>
> This table may be formatted as a dBase table or as a comma delimited text table.
>
> The first row of the land use look up table must contain the field names. The remaining rows will hold the required data.

Land Cover Look Up Table for SWAT input (dBase or ASCII)

dBase Table format for LUT is defined below (2 fields):

FieldName2	FieldFormat	Definition
VALUE	String	Number of map category
LANDUSE	String 4 chars	Corresponding SWAT landuse or urban code

Correspondingly, built-in land cover / land use LUT classes used as input to SWAT are:

"VALUE"	"LANDUSE"
1	RNGE
2	PAST
3	FRSD
4	WATR
5	AGRL
6	URBN

Land Cover Look Up Table for ArcSWAT import (dBase)

Four standard options are available in ArcSWAT to import classifications from external land cover datasets: the first option is to load the US Geological Survey Land Use / Land Cover (USGS LULC) classification. The second and third choices are to load US Environmental Protection Agency's National Land Cover Data classifications (NLCD 1992 or 2001. 2006 not yet implemented). The last option allows importing user defined lookup table, which can be provided in the same dBase format as SWAT built-in LUT.

Handling Projection in ArcSWAT

The ArcSWAT spatial datasets may be created in any projection (although the same projection must be used for all maps). The user can identify the type of projection and the projection settings within the interface when creating a new project. EnviroGRIDS at its kick-off meeting agreed to use as the official Geographic Coordinate System WGS84.

10 References

Anderson, J.R., Hardy, E. E., Roach, J. T., & Witmer, R. E., 1976, A land-use and land-cover classification system for use with remote sensor data.: Washington, DC: US.

Anyamba, A., and Tucker, C.J., 2005, Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981-2003: Journal of Arid Environments, v. 63, p. 596-614.

Balik Sanli, F., Filiz Bektas, B., and Goksel, C., 2007, Defining temporal spatial patterns of mega city Istanbul to see the impacts of increasing population: Environmental Monitoring and Assessment, v. 146, p. 267-275.

Baltsavias, E.P., 2002, Special section on Image Spectroscopy and Hyperspectral Imaging: (ISPRS Journal of Photogrammetry & Remote Sensing, v. 57, p. 169-170.

Baret F. , G.G.a.M.D.J., 1989, TSAVI: a vegetation index which minimizes soil brightness effects on LAI and APAR estimation, IGARSS' 89 and 12th Canadian Symposium on Remote Sensing, Vancouver, Canada, 10–14 July, 1989 (1989), pp. 1355–1358.: Vancouver, Canada, p. 1355–1358.

Berk. A., A.G.P., Bernsteina, L. S., Acharyaa, P. K., Dothea,H., Matthewa, M. W., Adler-Goldena,S. M., Chetwynd, J. H., Richtsmeiera,S. C.,, and Pukallb, B., Allredb, C. L., Jeongb, L. S., and Hokeb, M. L., 1999, MODTRAN4 Radiative Transfer Modeling for Atmospheric Correction, SPIE , Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research III, , Volume Volume 3756.

Bicheron P., Defourny P., Brockmann C, Schouten L., Vancutsem C, Huc M., Bontemps S., Leroy M., Achard F., Herold M., Ranera F., and O., A., 2008, GLOBCOVER: Products Description and Validation Report.

Bishop, M.P., 2001, Remote Sensing and Geomorphometry for Geoscience Applications in Mountain Environments, GSA Annual Meeting: Boston, Massachusetts.

Bosch, D.D., Sheridan J. M. , Batten H. L. , and G., A.J., 2004, Evaluation of the SWAT model on a coastal plain agricultural watershed: Trans. ASAE v. 47, p. 1493-1506.

Broge, N.H., and Mortensen, J.V., 2002, Deriving crop area index and canopy chlorophyll density of winter wheat from spectral reflectance data: Remote Sensing of Environment, v. 81, p. 45-57.

BSERP, 2004, Black Sea Contingency Plan to The Protocol on Cooperation in Combating Pollution of the Black Sea By Oil and Other Harmful Substances in Emergency Situations, *in* UNDP/GEF Black Sea Ecosystem Recovery Project (BSERP), A., ed.

Campbell, J.B., 1996, Introduction to Remote Sensing, Fourth Edition (Hardcover): New York, The Guilford Press

Chaplot, V., 2005, Impact of DEM mesh size and soil map scale on SWAT runoff, sediment, and NO3-N loads predictions: J. Hydrol, v. 312, p. 207-222.

Chavez, P.S.J., 1996, Image-based Atmospheric Corrections-Revisited and Improved.: Photogrammetric Engineering and Remote Sensing of Environment, v. 62, p. 1025-1036.

Cotter A. S., Chaubey I. , Costello T. A. , Soerens T. S. , and A., N.M., 2003, Water quality model output uncertainty as affected by spatial resolution of input data: J. American Water Res. Assoc, v. 39, p. 977-986.

Dawson, T.P., and Curran, P.J., 1998, A new technique for interpolating the reflectance red edge position: International Journal of Remote Sensing, v. 19, p. 2133-2139.

Demetriades-Shah, T.H., Steven M.D. and Clark J.A., 1990, High-resolution derivative spectral in remote sensing: Remote Sensing of Environment, v. 33, p. 55-64.

Di Luzio, M., Arnold, J.G., and Srinivasan, R., 2005, Effect of GIS data quality on small watershed streamflow and sediment simulations: Hydrol. Process, v. 19, p. 629-650.

Dogru, A.O., Filiz Bektas Balçık, C., Goksel, and Ulugtekin, N., 2006, Monitoring Coastal Dunes by Using Remote Sensing and GIS Integration in North West Part of Turkey: A Case Study of Kilyos Dunes: Fresenius Environmental Bulletin, v. 15, p. 1216-1220.

Du, Y., Teillet, P. M., & Cihlar, J., 2002, Radiometric normalization of multitemporal high-resolution satellite images with quality control for land cover change detection: Remote Sensing of Environment, v. 82.

ECBSea, 2009, Integrated Coastal Zone Management Strategy for Georgia, *in* EU funded Project Environmental Collaboration for the Black Sea (draft, i.c.v.o.O., 2009), ed.

Elvidge, C.D., 1990, Visible and near infrared reflectance characteristics of dry plant materials: International Journal of Remote Sensing, v. 11, p. 1775–1795.

EnviroGRIDS, 2008, Building Capacity For a Black Sea Catchment Observation and Assessment System supporting Sustainable Development, *in* 7th Framework Programme, T., Environment (including climate change),, ed., Description of Work: Bruxelles, EU FP-7.

Gassman, P.W., Reyes, M.R., Green, C.H., and Arnold, J.G., 2007, Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions: Transaction of American Society of Agricultural and Biological Engineers (ASABE), v. 504, p. 1211-1250.

Gitelson, A.A., and Merzlyak, M.N., 1996, Signature analysis of leaf reflectance spectra: algorithm development for remote sensing of chlorophyll: Journal of Plant Physiology v. 148, p. 494-500.

Halldórsdóttir, S.G., and Þorbergsson, H., 2004, Remote Sensing Coupled to a Database of Catchments and Coastal Zone, 12th Int. Conf. on Geoinformatics − Geospatial Information Research: Bridging the Pacific and Atlantic: University of Gävle, Sweden, p. 593-598.

Hay, G.J., and Castilla, G., 2006, Object-based image analysis: strengths, weaknesses, opportunities and threats (SWOT), OBIA, : The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

Jensen, J.R., 1996, Introductory digital image processing: a remote sensing perspective Prentice Hall, 526 p.

Jinguo, Y., and Zheng, N., 2007, Classification Using EO-1 Hyperion Hyperspectral and ETM Data, Proceedings of the Fourth International Conference on Fuzzy Systems and Knowledge Discovery - Volume 03, IEEE Computer Society.

Kardoulas, N.G., Bird, A. C. and Lavan, A. I. , 1996, Geometric Correction of SPOT and Landsat Imagery: A Comparison of Map and GPS Derived Control Points: Photogrammetric Engineering & Remote Sensing,, v. 62, p. 1173-1177.

Karpouzli, V., and Malthus, T., 2002, The empirical line method for the atmospheric correction of IKONOS imagery: International Journal of Remote Sensing, v. 24, p. 1143-1150.

Kartikeyan, B., Sarkar A., and Majumder, K.L., 1998, A segmentation approach to classification of remote sensing imagery: Journal of Remote Sensing, v. 19, p. 1695-1709.

Kaya, Ş., Müftüoğlu, O., Tüysüz, O., 2004, Tracing the Geometry of an Active Fault Using Remote Sensing and Digital Elevation Model: Ganos Segment, North Anatolian Fault Zone, Turkey: International Journal of Remote Sensing, v. 25, p. 3843-3855.

Kruse, F.A., Lefkoff, A.B., Boardman, J.W., Heidebrecht, K.B., Shapiro, A.T.,, and Barloon, P.J., and Goetz, A.F.H. „ 1993, The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging Spectrometer Data": Remote Sensing of Environment, v. 44, p. 145-163.

L.F.Janssen, L., Bakker, W.H., Gorte, B.G.H., Horn, J.A., Pohl, C., Reeves, C.V., Weir, M.J.C., and Woldai, T., 2001, Principaes of Remote Sensing An Introductory Text Book, *in* Janssen, L.F., ed., ITC Educational Textbook Series:.

Lathrop, R.G., 1988, The integration of remote sensing and geographic information systems for Great Lakes water quality monitoring: Wisconsin, University of Wisconsin.

Lehmann A., Ray N., Kideys A., P., W., and M., a.G., 2009, Connecting the EnviroGRIDS Black Sea Catchment Observation System to Integrated Coastal Zone Management The Ninth International Conference on the Mediterranean Coastal Environment: Sochi, Russian Federation, Proceedings of the Medcoast 09.

Liang, S., 2001, Atmospheric Correction of Landsat ETM+ Land Surface Imagery-Part I: Methods, : IEEE Transaction on Geoscience and Remote Sensing, v. 39.

—, 2004, Quantitative Remote Sensing of Land Surfaces,: New Jersey, USA, John Wiley and Sons.

Lillesand, M.T.a.K., W. R., 1994, Remote Sensing And Image Interpretation: New York, John Wiley & Sons, Inc, 750 p.

Major, D.J., Baret, F. and Guyot, G. , 1990, A ration vegetation index adjusted for soil brightness: International Journal of Remote Sensing, v. 11, p. 727-740.

Maselli, F., Gilabert, M.A. and Conese,C. , 1998, Integration of high and low resolution NDVI data for monitoring vegetation in Mediterranean environments: Remote Sensing of Environment, v. 63, p. 208-218.

Moos, D., and Wyatt, B.K., 1994, The CORINE biotopes project: A database for conservation of nature and wildlife in the European community: Applied Geography (Sevenoaks, England), v. 14, p. 327-349.

Pearson, R.L., and Miller , L.D., 1972, Remote mapping of standing crop biomass for estimation of the productivity of the short-grass prairie, Pawnee National Grasslands, 8th International Symposium on Remote Sensing of Environment: Michigan, USA, ERIM International, Ann Arbor, p. 1357–1381.

Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H. and Sorooshian,S. , 1994, A modified soil adjusted vegetation index: Remote Sensing of Environment, v. 48, p. 119-126.

Rahman, H., and G. Dedieu, 1994, SMAC: A Simplified Method for the Atmospheric Correction of Satellite Measurements in the Solar Spectrum: International Journal of Remote Sensing, v. 15, p. 123-143.

Rees, G., 2001, Physical principles of remote sensing Cambridge Cambridge University Press, 335 p.

Richards, J.A., 1993, Remote Sensing Digital Image Analysis, An Introduction, Springer-Verlag.

Richardson, A.J., and Wiegand, C.L., 1977, Distinguishing vegetation from soil background information: Photogrammetric Engineering and Remote Sensing v. 43, p. 1541–1552.

Richter, R., 1996, "A spatially adaptive fast atmospheric correction algorithm" International Journal of Remote Sensing, v. 17, p. 1201-1214.

Rouse J.W., H.R.H., Schell J.A., . Deering D.Wand Harlan J.C., 1974, Monitoring the vernal advancement of retrogradation of natural vegetation: NASA/GSFC, Type III, Final Report,, p. 1–371.

Schowengerdt, R.A., 1997, Remote sensing: models and methods for image processing Elsevier.

Seker D.Z. , and C. Goksel, S.K., N. Musaoglu and S. Kaya, 2003, Investigation of coastal morphological changes due to river basin characteristics by means of remote sensing and GIS techniques: Water Science and Technology., v. 48, p. 135-142.

Sims, D.A., and Gamon, J.A., 2002, Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages: Remote Sensing of Environment, v. 2, p. 331-354.

Skidmore, A.K., Ferwerda, J , Mutanga,O, Van Wieren, S, Prins, H. H. T, Filiz Bektas Balcik, Venus, V. , 2009, Forage quality of savannas - simultaneously mapping foliar protein and polyphenols for trees and grass using hyperspectral imagery: Remote Sensing of Environment (Online available).

Song C, W.C., Seto KC, Lenney MP 2001a, Classification and change detection using Landsat TM data: when and how to correct atmospheric effects?: Remote Sensing of Environment, v. 75, p. 230-244.

Song C, W.C., Seto KC, Lenney MP and Macomber S A. , 2001b, Classification and change detection using Landsat TM data: when and how to correct atmospheric effects?: Remote Sensing of Environment, v. 75, p. 230-244.

Strahler, A., Muchoney, D., Borak, J., Friedl, M., Gopal, S., Lambin, E., and Moody, A., 1999, MODIS Land Cover Product Algorithm, *in* Theoretical Basis Document (ATBD), V., ed.

Tanik A., Seker D. Z., Ozturk I., and C, T., 2008, GIS Based Sectoral Conflict Analysis in a Coastal District of Turkey, ISPRS Congress: Beijing, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII. Part B8. .

Teilet, P.M., 1986, Image correction for radiometric effects in remote sensing,: International Journal of Remote Sensing, v. 7, p. 1637-1651.

Townshend, J.R.G., Justice, C.O., Gurney, C., and McManus, J., 1992 The impact of misregistration on change detection: IEEE Transaction on Geoscience and Remote Sensing, v. 30, p. 1054-1060.

Turker, M., & Gacemer, A. O. , 2004, Geometric correction accuracy of IRS-1D PAN imagery using topographic map versus GPS control points.: International Journal of Remote Sensing v. 25, p. 1095-1104.

UNEP, 2005, One Planet Many People: Atlas of Our Changing Environment, Division of Early Warning and assessment (DEWA) United Nations Environment Programme (UNEP).

Vekua, T., Kochinashvili, T., Natsvlishvili, E., Naskidashvili, N., and Bakhtadze, Z., 1997, Rioni River Basin Environmental Hot Spots Study, *in* Bank/GEF, W., ed., Georgia ICZM Program/MIRP.

Vermote, E.F., Tanre´, D., Deuze´, J. L., Herman, M., & Morcrette, J. J. , 1997, Second simulation of the satellite signal in the solar spectrum: An overview. : IEEE Transaction on Geoscience and Remote Sensing, v. 35, p. 675-686.

Winchell, M., Srinivasan, R., Di Luzio, M., and Arnold, J., 2009, ArcSWAT 2.3 Interface for SWAT2005, User's Guide.